# PALYNOLOGY AND PALEOECOLOGY OF THE SAN MIGUEL LIGNITE DEPOSIT OF LATE EOCENE AGE, SOUTH TEXAS

Volume I

A Dissertation

by

JUDITH ANN GENNETT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 1993

Major Subject: Geology

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ABSTRACT

Palynology and Paleoecology of the San Miguel Lignite Deposit of Late Eocene Age, South Texas. (December 1993)

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Eight pollen and spore sequences from the high ash, high sulfur San Miguel lignite deposit indicate a Late Eocene, Jackson age. In general, the sequences follow a pattern, with high Nyssa kruschii and Rhoipites angustus percentages at the base, and high Cupuliferoipollenites sp. percentages at the top; the presence of Nyssa (tupelo) strongly suggests a freshwater swamp. Cluster and reciprocal averaging analysis reinforce these patterns, and suggest two vegetational-environmental gradients. One of these involves N. kruschii/R. angustus and Cupuliferoipollenites. The second involves these taxa in opposition to fern spores such as Laevigatosporites. It is not certain whether the gradients represent progressively shallower, deeper, or more saline environment. Similar palynomorph sequences were also recovered from the Momipites coryloides-dominated Late Eocene Lake Somerville lignites. The Lake Somerville lignites may represent a cyclic increase in depth and salinity, and the San Miguel lignites may have had an analogous depositional history.

No strong correlation was found in the San Miguel lignites between ash, sulfur, and palynomorph content.

Analysis of palynomorph samples from horizontal sequences indicates a great deal of lateral variability, but the use of reciprocal averaging and running averages show that vertical variability is greater and that, although the data is "noisy," vertical changes in palynomorph content are valid and meaningful.

# DEDICATION

For
Emma, Ian, and Erin

## ACKNOWLEDGMENTS

This study was funded in part by the Center For Energy and Mineral Resources. The San Miguel cores were provided by Sam Gowan; thanks also go to the drill crew including at various times Sam Gowan, Dave White, Stephanie Shelvey, Harlan Jennings, Glen Lowenstein, and Scott Armstrong. My field assistants at the Lake Somerville site were Emma Day-Gennett, Joshua Schoen, and John Jones. The Yegua sample from 29th Street in Bryan was collected by Chuck Thornton. Richard Day drafted Text-Figures 1-3, the "pollen diagrams," and the composite multivariate plots, using Generic CADD. Multivariate programs were provided by Warren Kovach and Bill Parker.

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# INTRODUCTION

## Historical Perspective

Fossil pollen and spores (palynomorphs) have often been used as tools to obtain paleoenvironmental information contained in sediments. Although palynomorphs in clastic sediments are useful in determining paleoclimates, clastic palynomorph spectra reflect a large regional, wind and water transported component. Palynomorph suites from coals probably represent a more local flora, and variation in these assemblages can be interpreted to show changes in the vegetation near the site of deposition.

The first palynomorph studies of lignites were done on the middle Eocene German Braunkohles by Potonié (1934), and later, Pflug (1950). Traverse's paper on the Oligocene Brandon lignites of Vermont, published in 1955, was the first American paper in this field. Traverse presented a pollen diagram from both the lignite and surrounding clastics, and made both water depth and climatic interpretations from these data. He favorably compared the Brandon paleoswamp to wetlands in present-day southeastern North America. More recent papers describing North American Tertiary (excluding Texas) lignite palynofloras include Miocene studies by Rachele (1976), Taggert and Cross (1980); Cross and Taggart (1983), Piel (1977), Martin and Rouse (1966); Yeend (1977); Wolfe et al. (1966); an Oligocene study by

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The format employed by Palynology is used for this dissertation.

Piel (1971); Eocene papers by Newman (1981), Hopkins (1967), and Hopkins and Sweet (1977); and Paleocene studies by Martinez and Urban (1971), Anderson (1960), Moore and Urban (1975), Leffingwell (1971), Spindel (1975), Kremp et al. (1961), Trotter (1963) and Griggs (1970).

## Introduction

This study details the pollen and spore composition of the Texas Eocene San Miguel lignites and the spatial changes that occur in this composition. There are several reasons for this undertaking. In the broadest sense, a general overview of the flora can provide a comparison with other palynofloras from other environments and ages, particularly from the Gulf Coast. Within lignites the type of vegetation indicated by the palynomorphs gives clues to the climate, the communities which formed the deposits, and by inference, the depositional environment of the deposit. Both vertical and horizontal variations in palynomorph composition indicate changes in environment that are often not elucidated by other methods. Changes in palynomorph content may be correlated with other variables of interest to coal geologists, such as coal quality. These changes may be a result of biological succession, which would extend our understanding of Eocene paleocommunities. The flora itself is a clue to a more precise date for the San Miguel lignites and associated units. In turn a compilation of the taxa present at San Miguel will enlarge the biostratigraphic data available to other researchers attempting to date Gulf Coast sediments. A study of the present-day ranges of

palynomorph taxa assignable to modern genera and species ranges will aid in the study of the regional climate during the Eocene.

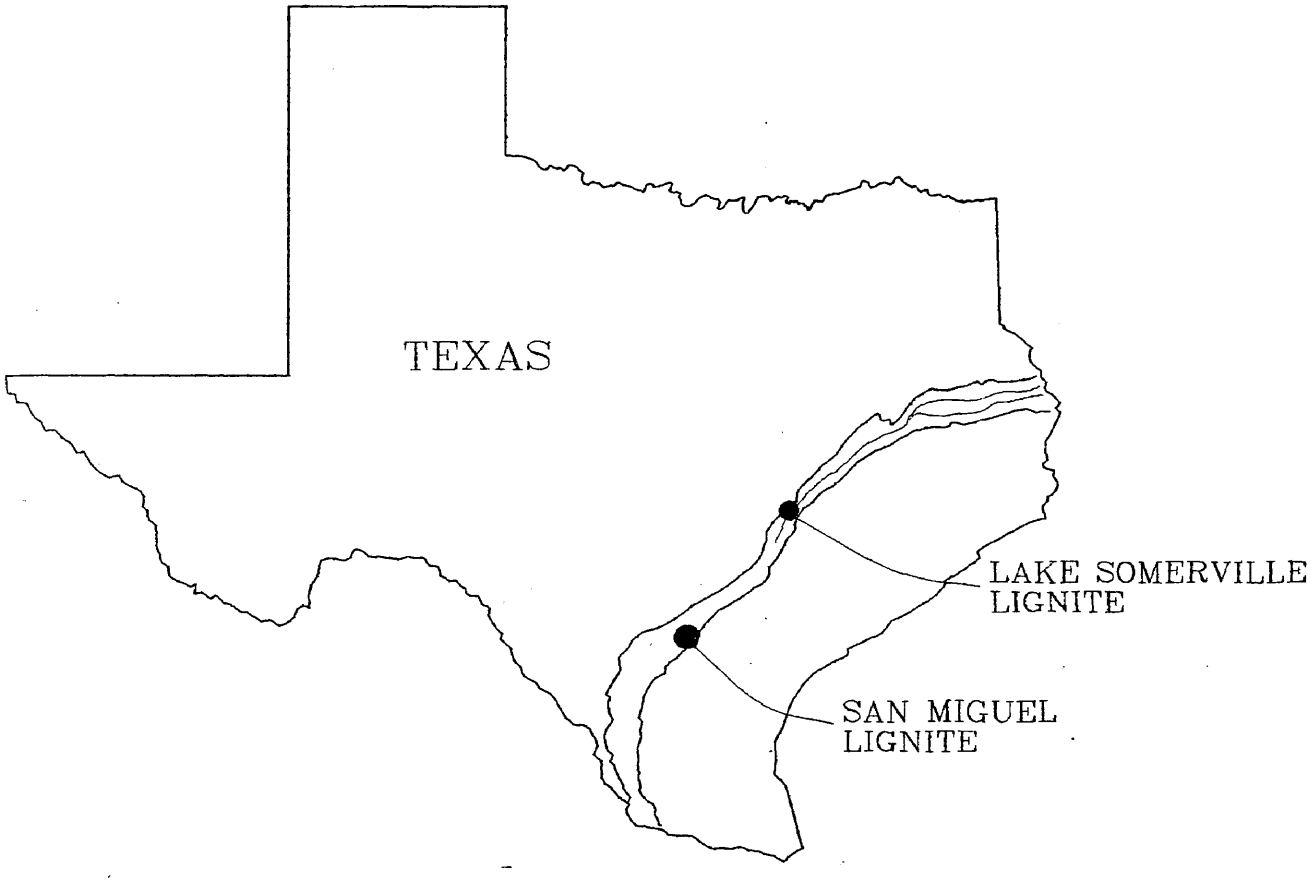
# CHARACTERISTICS OF THE DEPOSIT

## The San Miguel Deposit

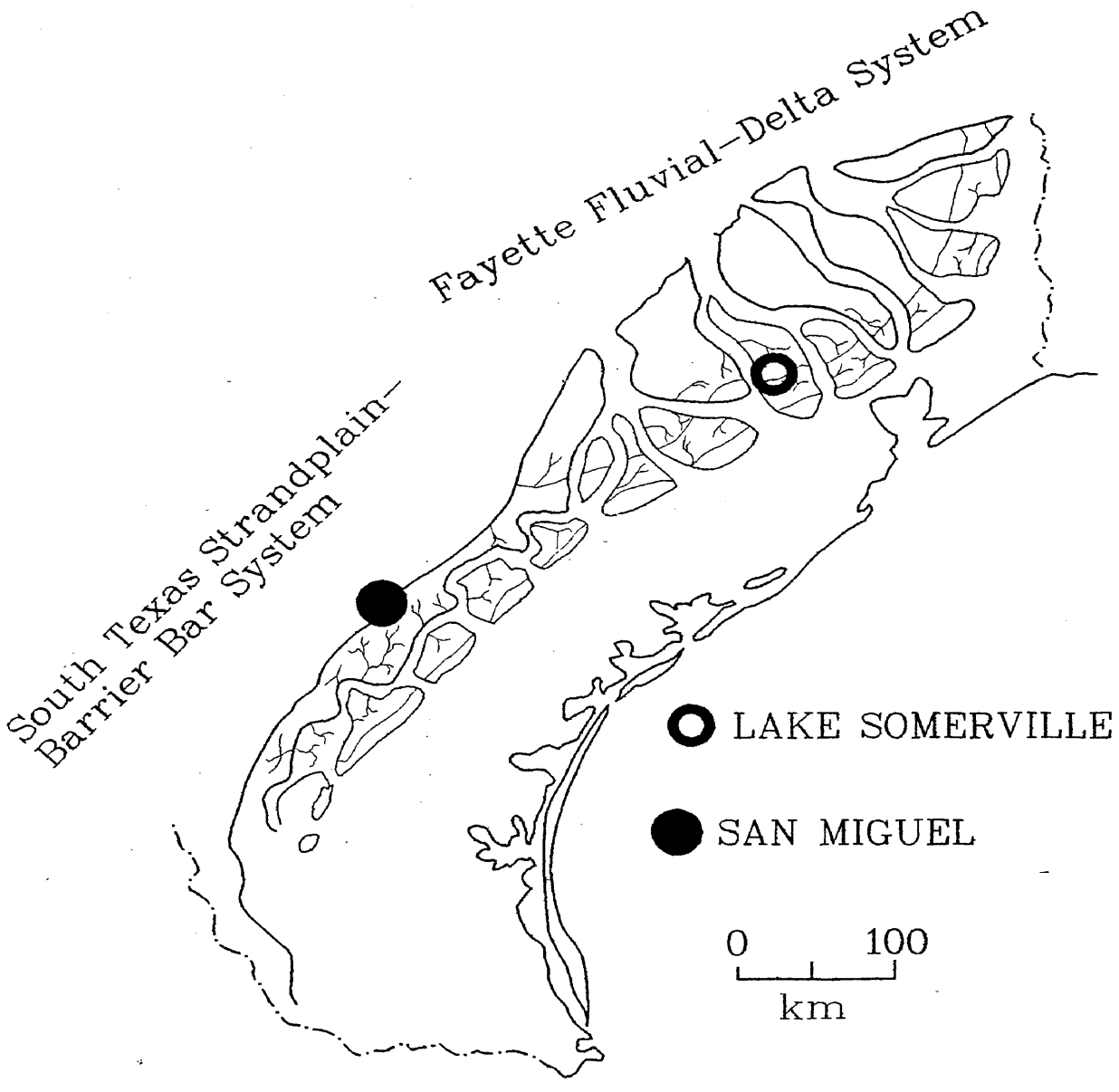
The San Miguel Lignite is a low quality but extensive deposit located in northeastern McMullen and southern Atascosa Counties, Texas (Text-Figure 1). Lignite from the San Miguel deposit averages 32% moisture, 25% ash, 2.0 % sulfur, and 5,318 Btu/lb. (L. Dick, written commun., cited in Ayers, 1986). It is Middle to Upper Eocene in age, and is referred to as "Yegua-Jackson" lignite because of the difficulty in establishing the Middle-Upper Eocene boundary in South Texas (Ayers and Kaiser, 1986).

In the area of this study, five major seams and several riders comprise the San Miguel. Gowan (1985) designated these seams, from the top down, as A, B, C, D, and E. These seams are separated by silty partings. At Gowan's Highwall section B, the A-B parting averages 0.25 m (.81 ft.) thick, the B-C averages 0.24 m (.78 ft.), and the C-D averages 0.30 m (.97 ft.). The total thickness of these three partings ranged to over 1.2 m (4 ft.) in Gowan's study area. Only the C and D seam are substantial in thickness. Gowan gave coal core thicknesses for the C seam of 0.84 to 0.95 m (2.75 to 3.1 feet). The thicknesses increases to the southeast. His core thickness for the D seam ranged from .85 m (2.8 ft.) to .98 m (3.2 feet).

The San Miguel lignites formed in what was, during the Late Eocene, part of the South Texas Strandplain-Barrier Bar System of Fisher et al. (1970). Text-Figure 2 shows both the barrier bar system and the Fayette




**Text-Figure 1. Location of the San Miguel and Lake Somerville lignites.**




**Text-Figure 2. Depositional systems in the Jackson Group of Texas during the Late Eocene.**

Fluvial-Delta System, which contributed clastic sedimentto the former barrier bars.

The exact mode of formation of these lignites has been controversial. According to Snedden (1979) and Snedden and Kersey (1981), these lignites formed in coastal wetlands at the landward side of a lagoon; partings in the lignite represent "fire-splays," formed by the rupture of river levees by the burning-off of surrounding peats during dry periods. A modern analogy is described by Staub and Cohen (1978) for the Snuggedy Swamp of South Carolina. Snedden's theory implies a fluvial source for the clastic partings. Gowan (1985), on the other hand, believed that a freshwater swamp formed behind a closed barrier bar. Temporary breaches in the bar brought in marine sediments, and saltmarshes replaced freshwater swamp vegetation. Coal petrographic work by Mukhopadhyay (1989), based largely on channel samples, indicated that the B and C seams were deposited in freshwater swamp-marsh environments because of the "...high ulminite content and low humodetrinite and liptodetrinite content..." (p. 78). He believed the A and D seams to have formed in saline marshes because of the "...unbanded and nonxylitic lithotype, rich humodetrinite and liptodetrinite," and "sparse marine phytoclasts (dinoflagellates)..." (p. 78).

## The Lake Somerville Deposit

The lignite beds at Lake Somerville (Text-Figure 1) may correlate with seams of the Manning Formation mined at the Gibbons Creek Mine in Grimes County, Texas (Yancey and Davidoff, 1991; T. Yancey, oral commun., 1993). The three lignite seams are separated widely by

siliciclastic deposits. The lower lignite occurs upon an erosion surface (paleosol) on top of a friable sandstone which overlies volcanic sediments (K. Phillips, oral commun., 1993). The lowest seam is 0.2 to 1.0 m thick, locally grades to a carbonaceous shale, and has a burrowed top (Yancey and Davidoff, 1991). Yancey (1992) also found a thin ashy zone near the base. This lower seam is separated from the middle lignite by silty shale overlain by sandstone. Yancey believes these burrowed shales, which contain marine diatoms (K. Phillips, oral commun., 1993), to represent flooding of the lignite with standing water. The sandstone is less burrowed and contains muddy interzones. Planar cross-beds appear near the top of the sand. Yancey and Davidoff (1991) described the middle lignite as "...1.0 m thick in the middle of the outcrop, and thickening toward the dam, with a variable mud content. The lignite contains a thin interbed of tuff near the top [10 cm. from the top] and the top is penetrated by small burrows filled with muddy sand from the overlying bed. Layers within the lignite and sands underlying the lignite are cut with root traces." (p. 101) Yancey (1992) described a similar sequence of shales and sandstones separating the middle lignite (referred to as the "upper lignite" in this paper) from an uppermost lignite layer.

The Lake Sommerville spillway lignites are encompassed in the Fayette Paleodelta system of Fisher et al. (1970) (Text-Figure 2). Gilmore (1981) believed that the lower lignite was "probably laid down in a low area between distributary channels [i.e., blanket peat] (p. 45)", whereas the upper lignite of this study may have been a "channel fill" lignite. Yancey and Davidoff (1991) hypothesized deposition by periodic flooding into

coastal plain swamps or lacustrine basins. They believed the regional setting to be "..a coastal plain which encompassed large fluvial channels separated by low energy plains with swamps and lake environments..." and "...part of a highstand systems tract." T. Yancey (oral commun., 1992) further explained that the lignite deposition was contained in a paleotopographic low. Water depth increased during lignite deposition, with the peak transgression occurring in the overlying shales. The paleosols at the top of the sands represent periods of maximum regression.

Mukhopadhyay (1989) investigated the coal petrology of the Lake Sommerville lignites. He considered the two lower seams to have been derived from "...blanket peats, primarily containing marsh vegetation, which was deposited at the transition of the upper and lower delta plain (p. 78)." Only one channel sample was examined from each seam in Mukhopadhyay's study.

Megafossils are found in abundance in clastic layers that occur higher in the section at Welch's park. Specimens collected by A. Raymond, R. Murry, and C. Thornton included seeds similar to those of modern Nyssa (A. Raymond, oral commun., 1987) and leaves similar to those of Oreoroa claibornensis Dilcher and Manchester 1986.

# PREVIOUS RESEARCH

## Geology and Paleontology of the San Miguel Lignites

Because of San Miguel's economic importance, numerous studies have been initiated on the deposit. Maxwell (1962) considered the deposit to be part of the Upper Yegua Formation. Kaiser (1974) referred to lignite of commercial thickness in McMullen and Atascosa Counties. He believed these lignites to be of Yegua-Jackson age. High ash and sulfur values, and low Btu/lb led Kaiser to conclude that the South Texas lagoonal lignites were the poorest quality lignites in Texas.

Fisher et al. (1970) located the San Miguel lignite in the South Texas lagoonal-coastal plain system. McNulty (1978) summarized available knowledge of the San Miguel, as well as presenting simplified cross sections of the seams.

Little previous research has been done on the palynology of the San Miguel. Mukhopadhyay (1989) selectively and qualitatively reported palynomorphs present in five channel and five lithotype samples from four San Miguel seams. In accordance with the views of Elsik (1978), he believed that Momipites was "...often associated with the marsh community (p. 58)" and used Nyssapollenites, Alangiopollis, Symplocoipollenites, and Sphagnum as swamp indicators. In seams B and D, "marsh" pollen was more abundant than "swamp" pollen. Nyssa and minor Engelhardia were observed in seams C and D. Mukhopadhyay noted that the San Miguel contained less Momipites than East Texas lignites of the same age.

Gowan (1985) reported mostly dicotyledonous woody fragments from the San Miguel coal seams. In addition,

Gowan found leaf impressions, which he believed to represent both monocotyledonous and dicotyledonous plants. Lath shaped plant fragments present in the partings were believed to belong to monocotyledonous taxa, notably, "...grasses, sedges, and reeds..." with a few Typha (cattail) leaves. Gowan also described pyritized roots.

The coal petrology of the ten San Miguel lignite samples led Mukhopadhyay (1986, 1989) to believe that the "...vegetation was dominantly of a reed marsh type (1986, p.139)." Dinoflagellates were observed in the D seam samples. This evidence led Ayers (1986) to consider the San Miguel to have formed in a "...fresh-water reed/marsh complex (p. 57)". Mukhopadhyay (1989) believed seams A and D to have been deposited in a marsh environment behind a barrier bar and that seam B and C peats formed in a fresh-water swamp-marsh barrier-bar environment.

## Palynology

The Eocene palynomorph taxonomy and biostratigraphy of the Gulf Coast area have been described in papers by Engelhardt (1964), Fairchild and Elsik (1969), Tschudy (1970), Tschudy and Van Lonen (1970), Elsik (1974), Elsik and Dilcher (1974), Saunders et al. (1974), Martinez-Hernández et al. (1980), Jones and Gennett (1991) and Frederiksen (1980a, 1988). Details of these papers are given in Tables 1 and 2.

Table 1. Palynological characteristics of Claiborne lignites.

| Site & Author | Stratigraphy | Samples | Dominant Taxa | Noteable Taxa |
|---|---|---|---|---|
| Palofax Mine (Webb Co., TX) Mukhopadyay (1989) | Bigford Fm. Early Claiborne | 1 | "Unidentified pollen referred to as Tricolpites, Tricolporites, Nudopollis terminalis | Platycarya Nudopollis |
| San Ignacio (Tamaulipas, Mexico) Martinez-Hernandez and others (1980) | Bigford Fm. Early Claiborne | 2 | tricolpates and tricolporates | Aesculidites |
| Columbia (Nuevo Laredo, Mexico) Martinez-Hernandez and others (1980) | Bigford Fm. Early Claiborne | 5 | tricolpates and tricolporates | Nudopollis Aesculidites |
| Lake Casa Blanca (Webb Co., TX) Westgate and Gee | Laredo Fm. Middle Claiborne (Marginal Marine) | 1 | Not Given | Spinozonocolpites (Nypa) |
| Panola Co., MS Frederiksen (1981) | Middle Claiborne | 1 | Cupuliferoidaepollenites Quercoidites microhenricii | Nudopollis absent |
| Tate Co., MS Frederiksen (1981) | Middle Claiborne | 1 | Cupuliferoipollenites Siltaria Quercoidites microhenricii | |
| Miller Clay Pit (Henry Co., TN) Potter (1976) | Cockfield Fm. Late Claiborne (Oxbow Lake) | 27 | Cupuliferoipollenites (with palms at top of seam) | Nudopollis Aesculidites Anacolosidites |
| Hinds Co., MS Frederiksen (1981) | Cockfield Fm. Late Claiborne | 1 | Momipites | Nudopollis absent |
| Madison Co., TX Elsik (1978) | Yegua Fm. Late Claiborne (Dominantly Fluvial) | 3 | Momipites Nyssa | Amanoa |
| Carter Creek (Brazos Co., TX) This Study | Yegua Fm. Late Claiborne | 1 | Rhoipites angustus Momipites, Nyssa Liliacidites | Nudopollis absent |

Table 2. Palynologial characteristics of Jackson lignites.

| Site & Author | Stratigraphy | Samples | Dominant Taxa | Noteable Taxa |
|---|---|---|---|---|
| Fayette Co., TX<br>Frederiksen (1981) | Manning Fm. | 3 | Momipites<br>Caprifoliipites | Nudopollis<br>absent |
| Walker Co., TX<br>Frederiksen (1981) | Manning Fm. | 2 | Momipites<br>Caprifoliipites | Nudopollis<br>absent |
| Gibbons Creek<br>(Grimes Co., TX)<br>Frederiksen (1981) | Manning Fm. | 9 | Momipites, sometimes<br>with Caprifoliipites<br>Cyrillaceaepollenites<br>ventosus,<br>Cupuliferoipollenites | Nudopollis<br>absent |
| Brazos and<br>Grimes Co., TX<br>Elsik (1978) | Manning Fm. | ? | Momipites, Nyssa,<br>sometimes C. ventosus | |
| Miguel Aleman<br>Cupuliferoipollenites<br>Tamaulipas, Mexico<br>Martinez-Hernandez<br>and others (1980) | Jackson Group | ? | Momipites<br><br>Cicatricosisporites<br>"Tricolporopollenites" | <br><br>present |
| Lake Somerville<br>Washington Co., TX<br>This Paper | Manning Fm. | 20 | Momipites, sometimes<br>Cupuliferoipollenites<br>Cicatricosisporites | |

Paleoecology

Several attempts have been made to correlate Paleogene Gulf Coast palynomorphs with paleoenvironment. Gray (1960) made preliminary attempts to classify the ecological origin of Middle Eocene palynomorphs from Alabama. Nichols (1970) and Nichols and Traverse (1971) correlated broad depositional systems with palynomorph content in Paleocene Texas lignites; their central Texas tidal lagoon pollen spectra were characterized by chenopod (saltbush) pollen. Potter (1976) described a pollen sequence from an inland ox-bow lake from the Middle Eocene of Tennessee.
is lignite seam was characterized by low pollen diversity and was dominated by Cupuliferoipollenites, which he believed to have been derived from wetland plants. Using these data, he was able to determine floral changes in this unit. High diversity in clastic samples was accompanied by large numbers of Cupuliferoidaepollenites grains, which he interpreted as fluvially transported from nearby dry land trees. Elsik (1978), in a review of the palynology of Texas Paleogene lignites, attempted to differentiate swamp and marsh floras. He thought that marsh vegetation was represented by the palm genera Liliacidites and Calamuspollenites-Arecipites, as well as sedge (Carex). Frederiksen (1981) analyzed samples from a number of Eocene and Oligocene Gulf Coast lignite and shale samples and was able to contrast floras from various general environments. His brackish water sediment samples yielded essentially a freshwater wetland pollen flora. Mancini (1981, 1983) used the absence of Nyssa and Taxodium pollen to support his hypothesis that the Paleocene Oak Hill Lignite originated as a deltaic coastal marsh. Gee and Westgate (1989) hypothesized

mangrove swamps on the Middle Eocene lower Texas Gulf Coast from the presence of Nypa in lignite samples.

Frederiksen (1985) also presented a general review of Early Tertiary plant paleoecology in which he outlined communities and hypothesized environmental requirements of selected taxa. He believed that plant successions inferred from lignite seams were probably not autogenic, but were likely caused by changes in water level.

# METHODS

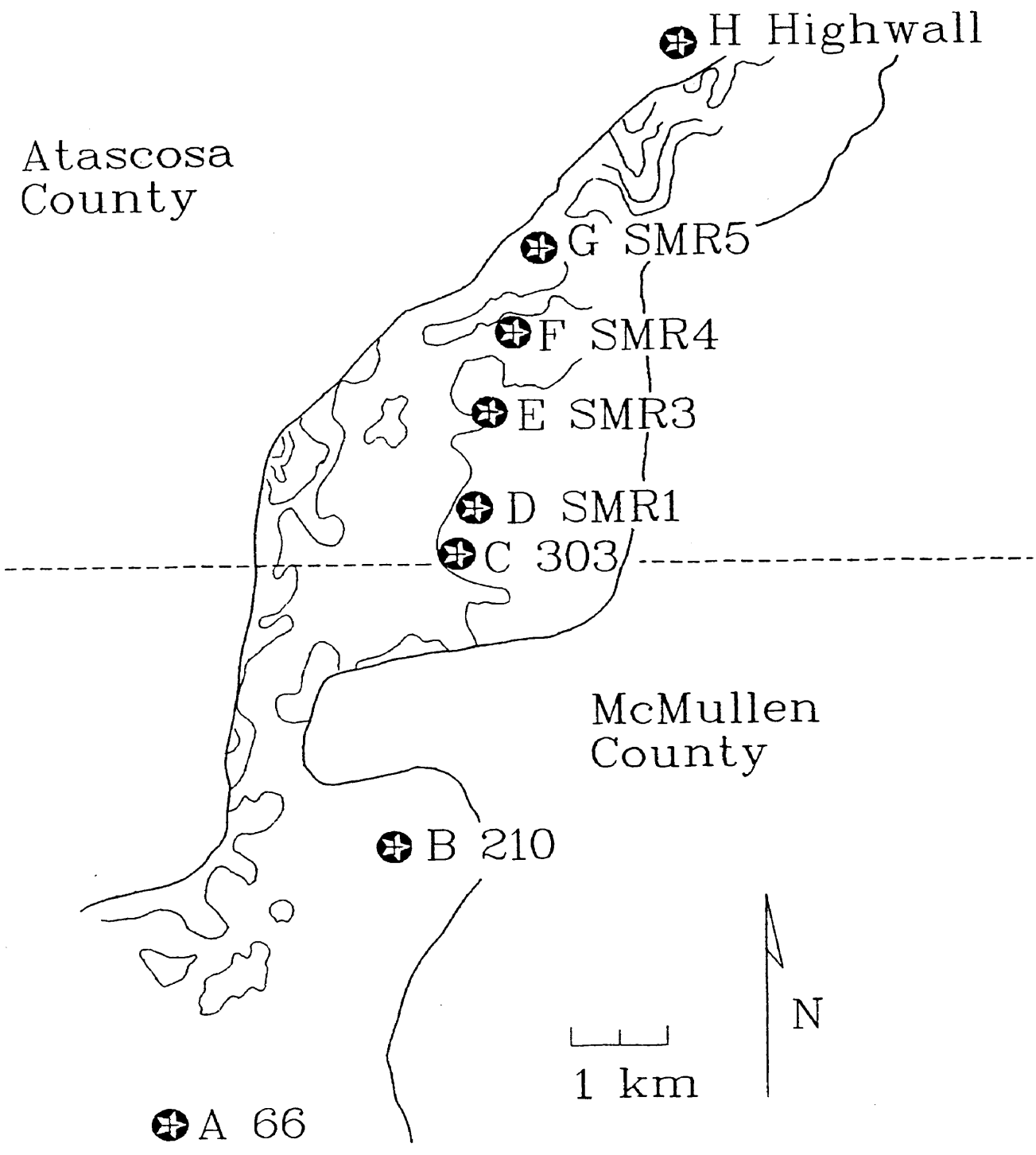
As has been discussed in the introductory section, detailed studies of palynomorphs can yield more detailed and useful information about lignites than the cursory palynological studies often employed. In this study, I used methods pioneered by Quaternary palynologists in order to acquire this detailed information. One of these methods, also used by Traverse (1955) among others, was sequential counts. These counts allow the detection of a sequence of paleofloras at the sample site. Several cores were used to compare these sequences in different areas of the swamp. Pollen concentrations were obtained in order to compare the actual amount of various palynomorphs in the different samples of lignites. Confidence intervals and running averages were computed in order to determine the importance of variation in these sequences. Other statistical techniques, such as multivariate analysis and diversity were "borrowed" from other types of paleontology. These methods sometimes "point out" features in the data not readily discernable by more subjective analyses.

Pollen and spores were analyzed from sections of seven cores through the San Miguel lignite, as well as from a seam in a highwall section (Text-Figures 3-11). Cores SM-66 OB (Sequence A in this study), SM-210 OB (Sequence B), and SM-303 OB (Sequence C) were drilled by Beacon Construction Co. previous to this project. Cores SM-1 (Sequence D), SM-3 (Sequence E), SM-4 (Sequence F), and SM-5 (Sequence G) were drilled during the spring of 1985 using the Texas A&M University Mobile Drill rig.

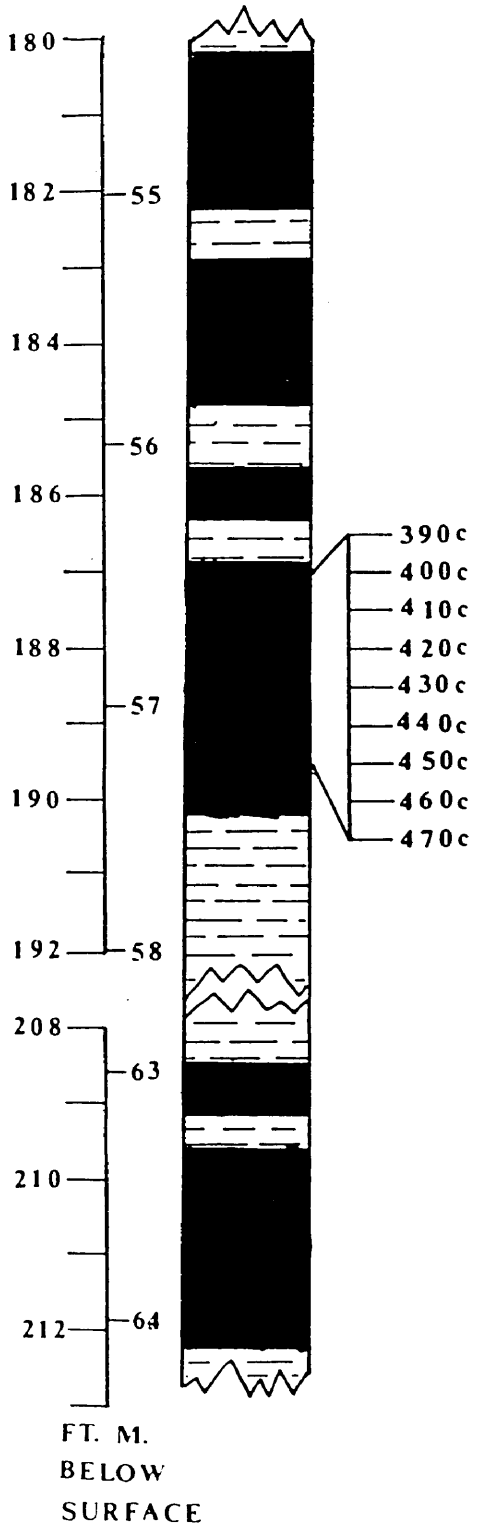
The latter sites were chosen by S. Gowan and traversed a thickening in the B seam. Samples from one high wall, Highwall A of Gowan (1985) (sequence H) were collected in the fall of 1984. The eight sections form a southwest-northeast traverse across the deposit, with Sequences C through G most closely spaced.

A vertical series of samples was removed from the cores and highwall at 10 cm intervals. A continuous sequence of samples, including partings and some overburden was analyzed for cores 210 and SM-3 (Sequence E). Because of poor recovery of palynomorphs from the partings and seams A and B, further processing involved seams C, D, and E only. Although all cores contain the C seams, cores SM-66 OB (Sequence A) and SM-1 (Sequence D) lack the D seam due to poor core retrieval. The E seam is present only in the SM-3 and SM-4 (Sequences E and F) cores.

Sampling from the Highwall involved the C seam only; the base of the D seam was below the base of the pit. Horizontal samples were taken at stations 6m (20 feet, as measured by Gowan, 1985) apart along the base of the seam and along an ash layer within the seam. Ten horizontal and seven vertical samples were taken at ten cm intervals at Station 7.

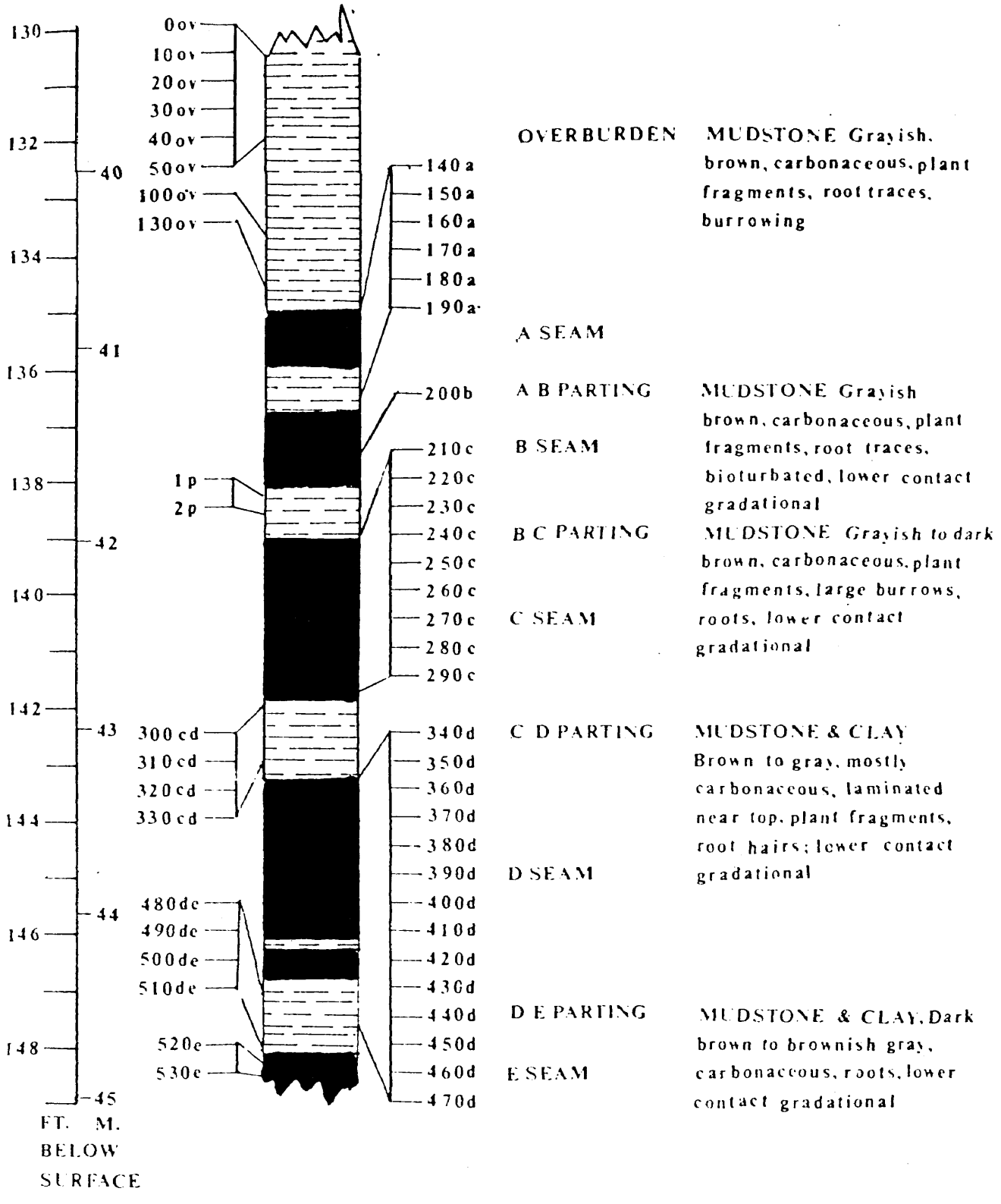



Text-Figure 3. Locations of cores and highwall section in the San Miguel Lignite.

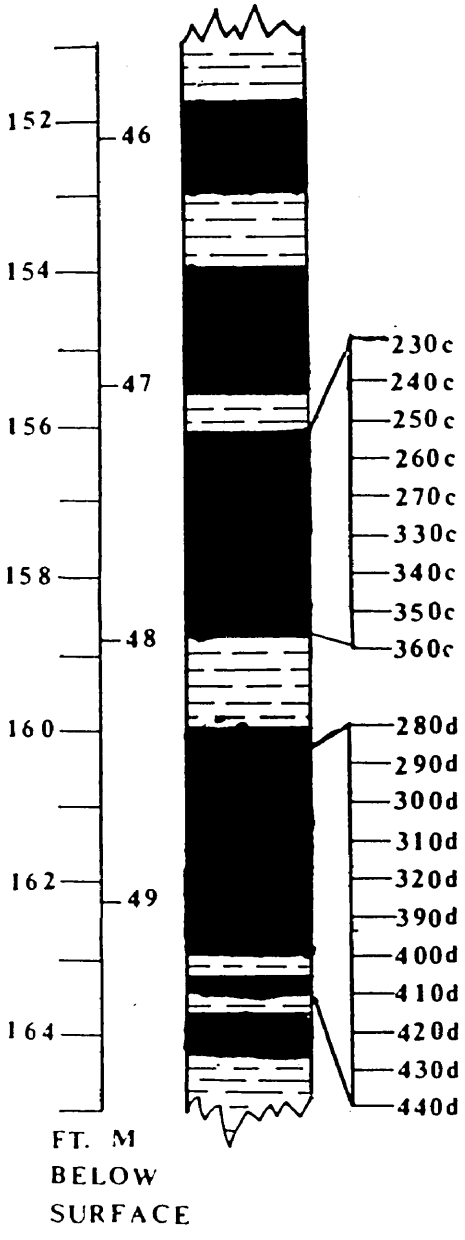



| | |
|---|---|
| OVERBURDEN | Dark to grayish brown, minor lignite seams, carbonaceous, |
| A SEAM | burrowed |
| A B PARTING | MUDSTONE Brown, carbonaceous some lamination and root traces |
| B SEAM | |
| BC PARTING | MUDSTONE Grayish brown, bioturbated, root traces, plant fragments, leaves at base |
| C SEAM | |
| C.D PARTING | MUDSTONE Brown to green, carbonaceous, at times laminated plant fragments, root traces |
| D SEAM | |
| | MUDSTONE Brownish white; bioturbated, root traces, plant fragments, glass shards |

Text-Figure 4. Location of Sequence A Samples in core SM-66 OB.

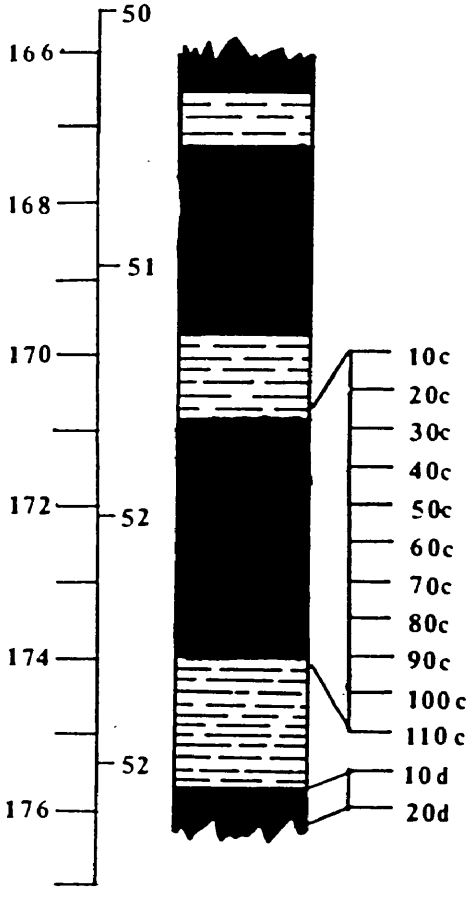



Text-Figure 5. Location of Sequence B Samples in core SM-210 OB.




| | |
|---|---|
| OVERBURDEN | MUDSTONE Brown, carbonaceous, rooted, burrowed |
| A SEAM | |
| A B PARTING | MUDSTONE Brown to dark brown, bioturbated, burrowed, lower contact gradational |
| B SEAM | |
| B C PARTING | MUDSTONE Brown, carbonaceous, root traces, organic debris |
| C SEAM | |
| C D PARTING | MUDSTONE Grayish to dark brown, laminated near base, wood, rooted, plant fragments, burrows, lower contact gradational |
| D SEAM | |
| D E PARTING | MUDSTONE Dark brown, carbonaceous, root traces, plant fragments, bioturbated |
| E SEAM | |

Text-Figure 6. Location of Sequence C Samples in core SM-33 OB.




A SEAM

A B PARTING MUDSTONE Brown to grayish brown, carbonaceous, burrowed and laminated toward base, lower

B SEAM contact gradational

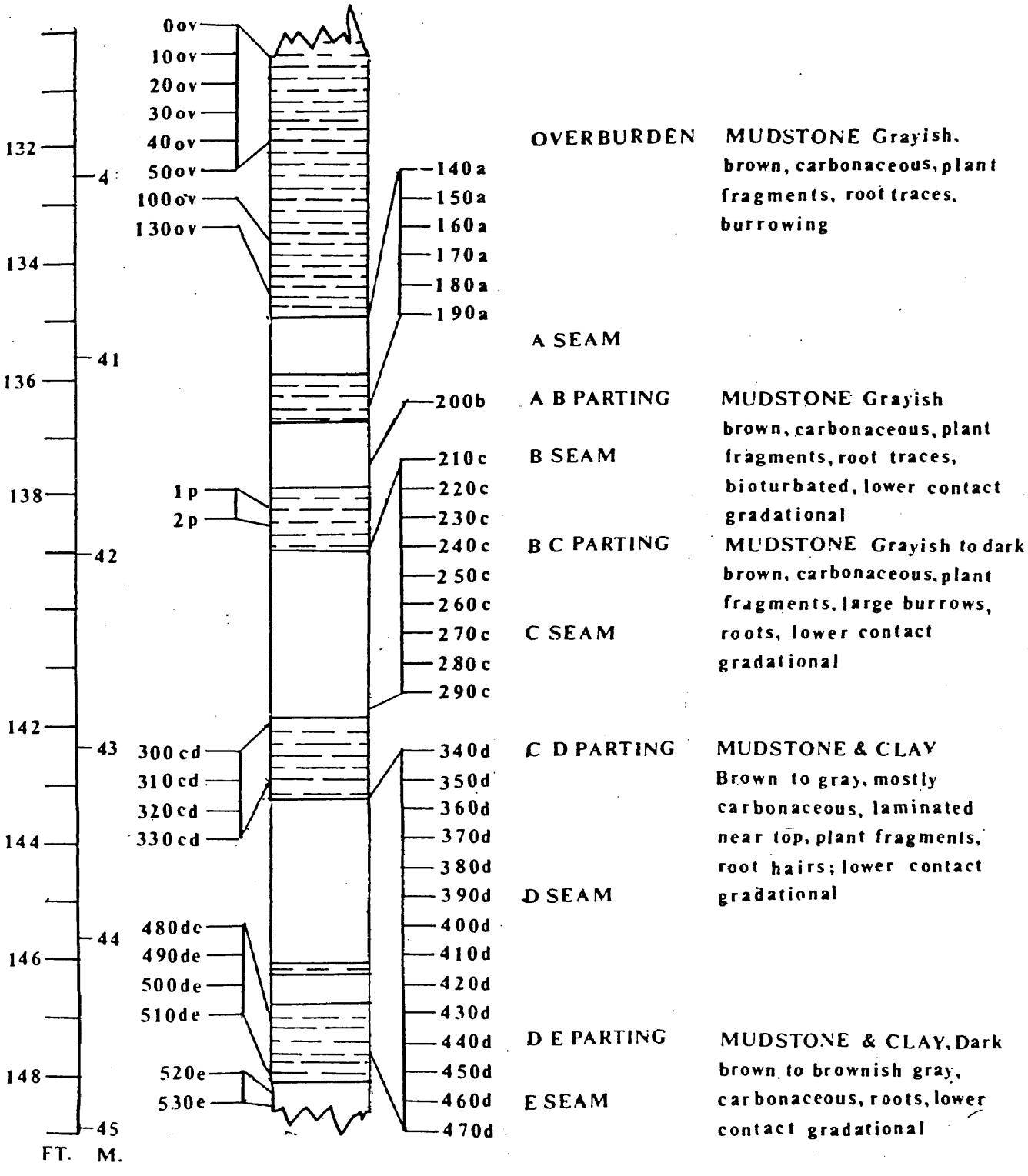
B C PARTING MUDSTONE Dark to grayish brown, carbonaceous, lower contact gradational

C SEAM

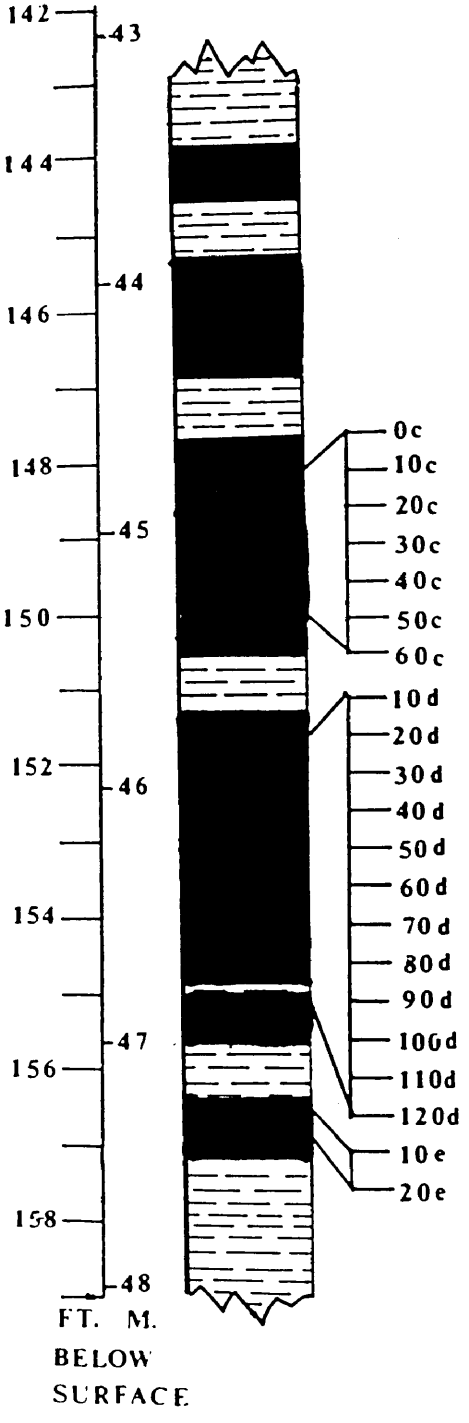
C D PARTING MUDSTONE Dark to grayish brown, clay layer in upper half, plant fragments, lower contact

D SEAM gradational

Text-Figure 7. Location of Sequence D Samples in core SMR-1.

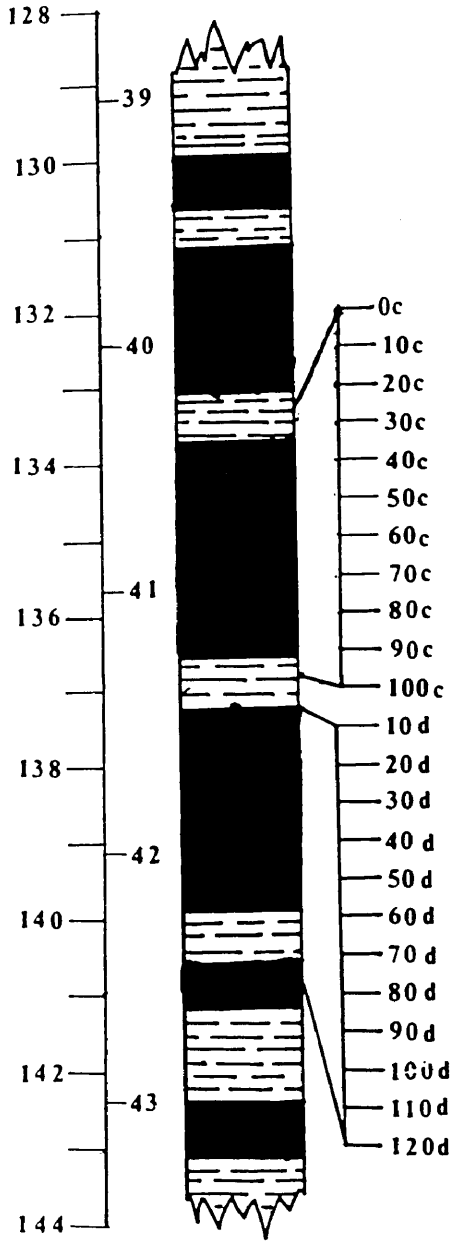



Text-Figure 8. Location of Sequence E Samples in core SMR-3.




| | |
|---|---|
| OVERBURDEN | MUDSTONE Dark brown, carbonaceous, lignite fragments; |
| A SEAM | bioturbated, plant fragments |
| A B PARTING | MUDSTONE Brown, carbonaceous, bioturbated, rooted, lower contact gradational |
| B SEAM | |
| B C PARTING | MUDSTONE Brown, carbonaceous, rooted, plant fragments, lower contact gradational |
| C SEAM | |
| C D PARTING | MUDSTONE Brown, carbonaceous, laminated near top, root traces, plant fragments |
| D SEAM | |
| D E PARTING | MUDSTONE Brown to gray, carbonaceous near top, rooted, |
| E SEAM | plant fragments, lower contact gradational |
| UNDERBURDEN | SILTSTONE greenish gray, carbonaceous, bioturbated, rooted, plant fragments |

Text-Figure 9. Location of Sequence F Samples in core SMR-4.




OVERBURDEN MUDSTONE Brown, calcareous at base, root traces; lower contact gradational

A SEAM

AB PARTING MUDSTONE Brown, carbonaceous to lignitic, bioturbated, root traces, plant fragments, lower contact gradational

B SEAM

BC PARTING MUDSTONE Brown, carbonaceous, bioturbated, root traces, plant fragments, lower contact gradational

C SEAM

CD PARTING MUDSTONE Brown; carbonaceous, burrowed; rooted, plant fragments, lower contact disturbed

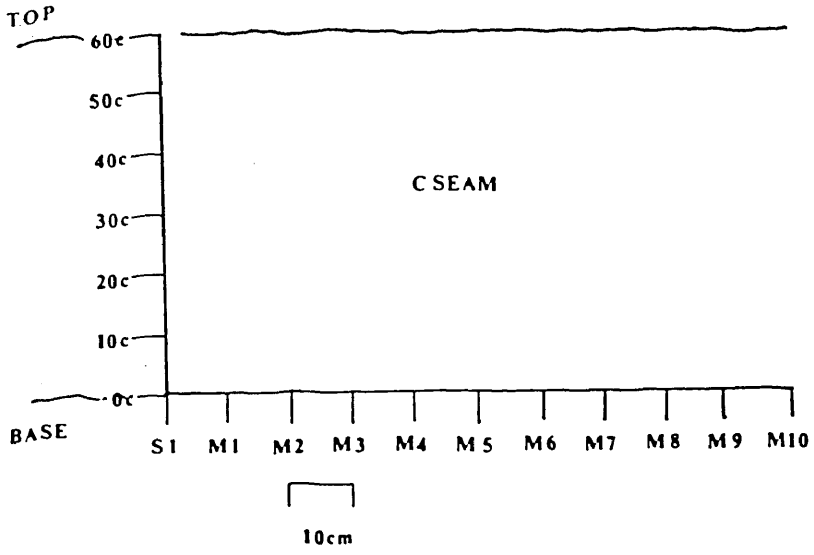
D SEAM

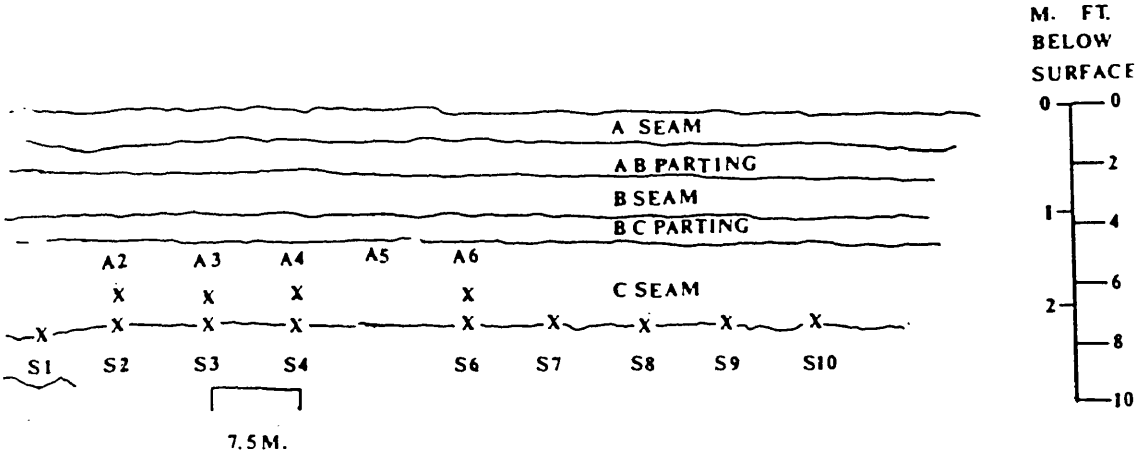
DE PARTING MUDSTONE Brown to brownish gray, carbonaceous near base, burrowed, root traces, plant fragments, lower contact gradational

E SEAM

FLOOR MUDSTONE Greenish gray, laminated, bioturbated, root traces; plant fragments

Text-Figure 10. Location of Sequence G Samples in core SMR-5.



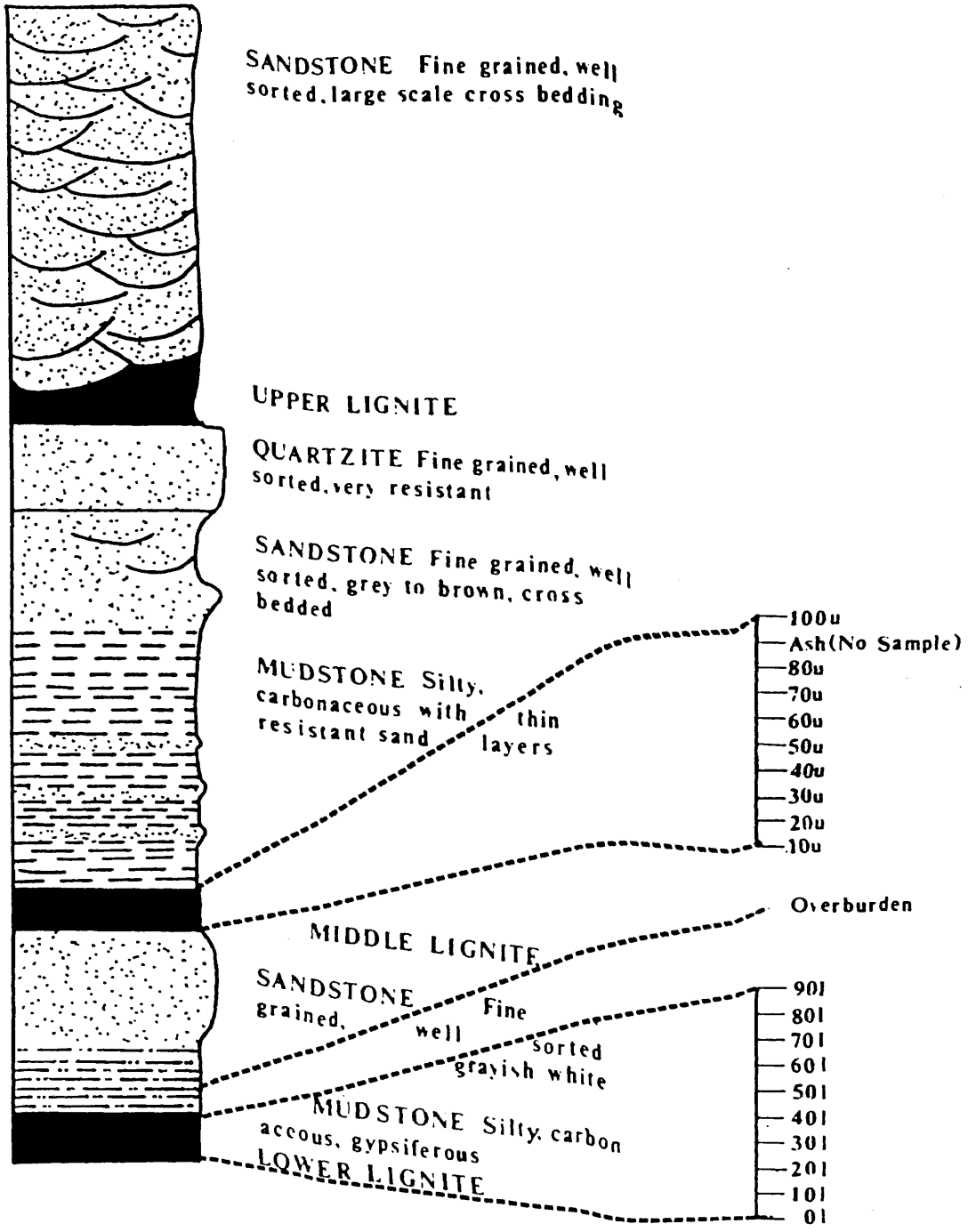




Text-Figure 11. Location of Sequence H and horizontal samples in Highwall A.

Vertical samples were also taken at 10 cm intervals from the bottom two lignite seams cropping out at the Lake Somerville spillway in Washington County, Texas (Text-Figure 12). Within the intervening shales and sands, samples were taken at 1 m intervals; only one of these samples yielded pollen.

Samples were processed using standard techniques (Doher, 1980). Core 210 was processed by EXXON in Houston, TX. Samples were treated with Hcl to remove carbonates, HF to remove quartz, $HNO_3$ to oxidize lignin, $NH_3OH$ to oxidize humic compounds, sonication using darvan to remove the remaining organic material, and heavy liquid separation using ZnBr to remove the remaining mineral material. Slides were mounted in castolite, a rigid mounting medium. The SMR-3 (Sequence E) core was processed in the same manner in the Palynology Laboratory at Texas A&M, and samples were mounted, as were samples from succeeding cores, in silicone oil. The use of silicone oil allowed the palynomorphs to be rolled and examined from various angles, making possible the identification of a higher proportion of the palynomorphs than did the use of a rigid medium. Samples from other cores consisted of lignite only and heavy liquid separation was deemed unnecessary and therefore omitted. Most samples from these cores were processed in the Paleontology Prep Room, Geology Dept., at Texas A&M.

For most samples, a minimum of 200 pollen and spore (excluding Lycopodium) grains were counted. Spores were included in the count because of their importance in wetland ecology; the history of the wetland that formed the San Miguel lignite was the object of study, not the history of the regional flora. If one slide yielded less than 25 grains, counting was discontinued. If,




Text-Figure 12. Location of samples in the Lake Somerville outcrop.

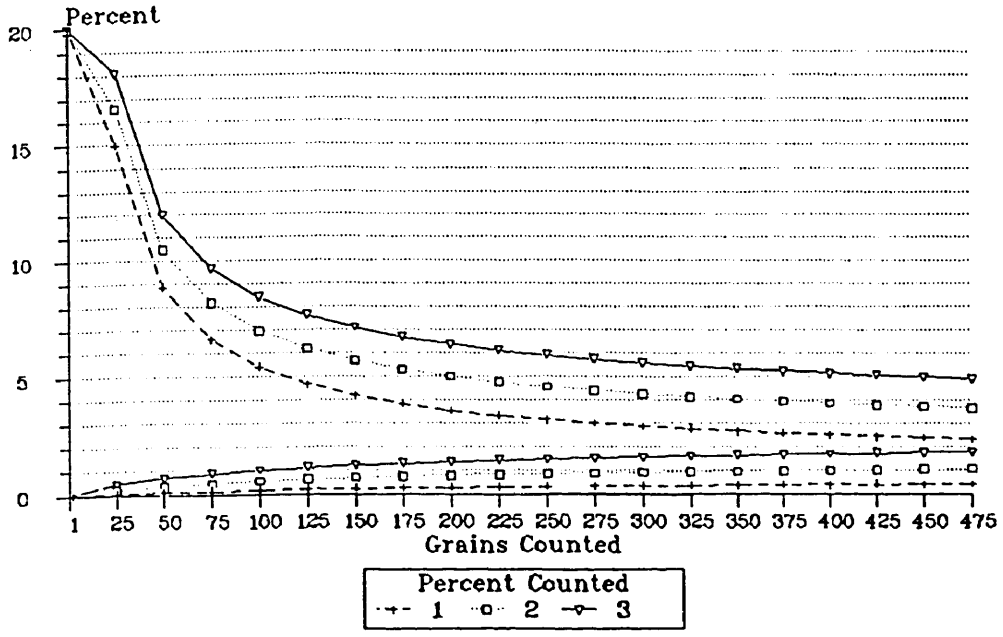
after three slides, a count of 200 was not attained, aminimum of 150 grains was counted. "Indeterminable" grains could not be identified because of poor condition and were not included in the palynomorph sum. Unidentifiable prolate, tricolporate grains with a long axis measuring approximately 15 μm were very common in some samples from core SMR-3 (sequence E). These grains were designated as "degraded small tricolporates" and were included in the pollen sum. "Unknown" grains were in good condition, but could not be assigned to previously named taxa; these grains were not included in the pollen sum. These grains are described in Appendix 1. Fungal spores were also counted outside of the palynomorph sum.

Controversy exists as to the ideal number of pollen grains to count. Rull (1987), after reviewing the literature, stated: "The general opinion is that each situation requires counting a different number of grains and no standard size can be fixed....an arbitrary lower limit of 200-300 grains is the most common criterion." (p. 471) Rull used the point where the slope, (i.e. differences between adjacent percentages) in the width of the 95% confidence interval approaches zero as an indicator of reproducibility. He considered a 200 grain count adequate above this number there is no significant shift in the width of the confidence intervals. This relatively low figure is not adequate, however, to accurately represent true percentages of uncommon grains; for taxa whose true percentage is 1% of the sample, it would be necessary to count 1620 grains. A total of 36,221 pollen grains were tallied from the San Miguel lignites and 4086 from the Lake Somerville lignites.

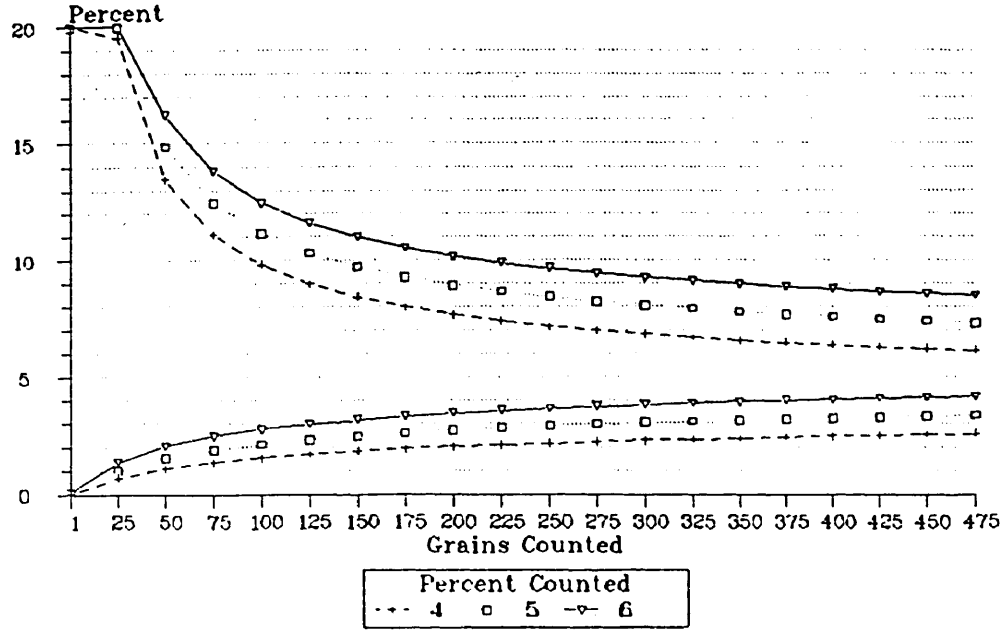
Moore and Webb (1978) demonstrated that a count of 150 grains is accurate for taxa comprising 20% or more of the pollen sum.

Text-Figures 13-19 show the effect of the number of grains counted on the size of the 95% confidence interval of various counted percentages. For example, if a count of 50 grains is made, the true value of a 5% counted value for a specific taxon has a 95% likelihood of being between 1.6% and 14.8% (Text-Figure 14). If 200 grains are counted, then this interval becomes 2.8% and 9.0%; if 400 grains are counted, then these values become 3.2% and 8.0%. In this case, a count twice as large would be necessary to narrow the 95% confidence interval by 2%. There is little available information on the actual meaning of the percentage values of Early Tertiary palynomorph counts, and consequently the precision attained in a count of 200 grains was deemed adequate in this study.

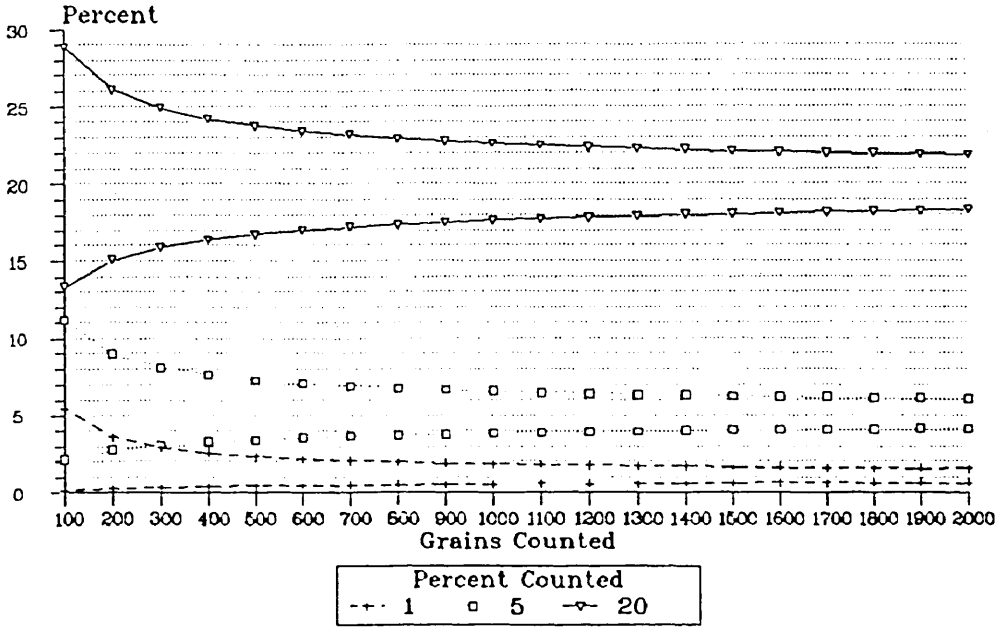
A tablet of Lycopodium "spike" was added to the final two cores to be processed, SM-4 (Sequence F) and SM 303-OB (Sequence C). The "spike" was added in order to determine pollen concentration, an estimate of the actual number of palynomorphs in a given volume of sediment. Additional interpretations can be made from these estimates, especially if a time frame is available for sediment deposition. Lycopodium was used because it is easy to identify and distinct among the Tertiary pollen and spores in these samples. These Lycopodium spores were counted outside of the palynomorph sum.



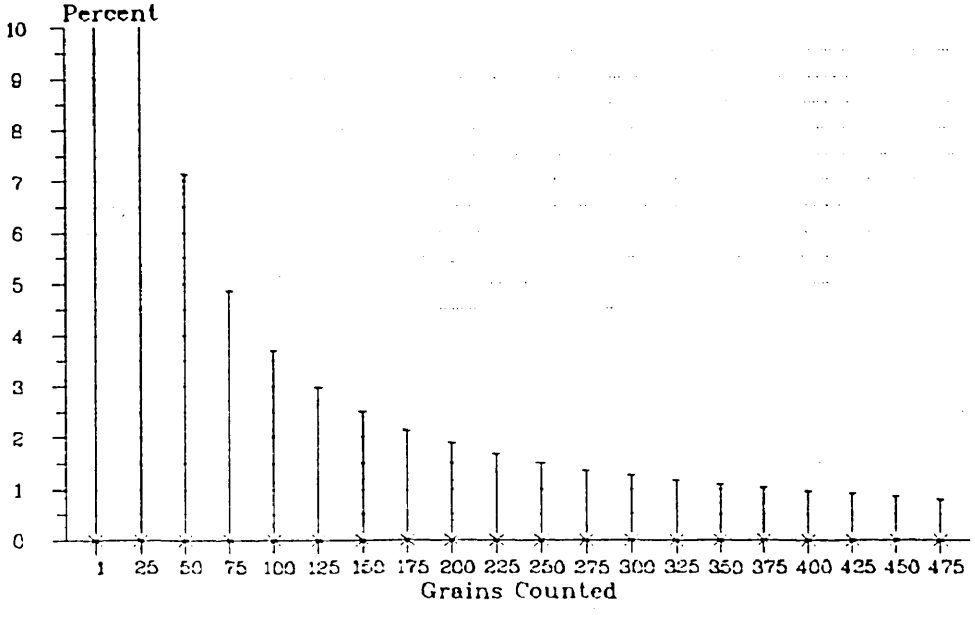

Text-Figure 13. 95% confidence intervals for counted percentages of 1% to 3%.



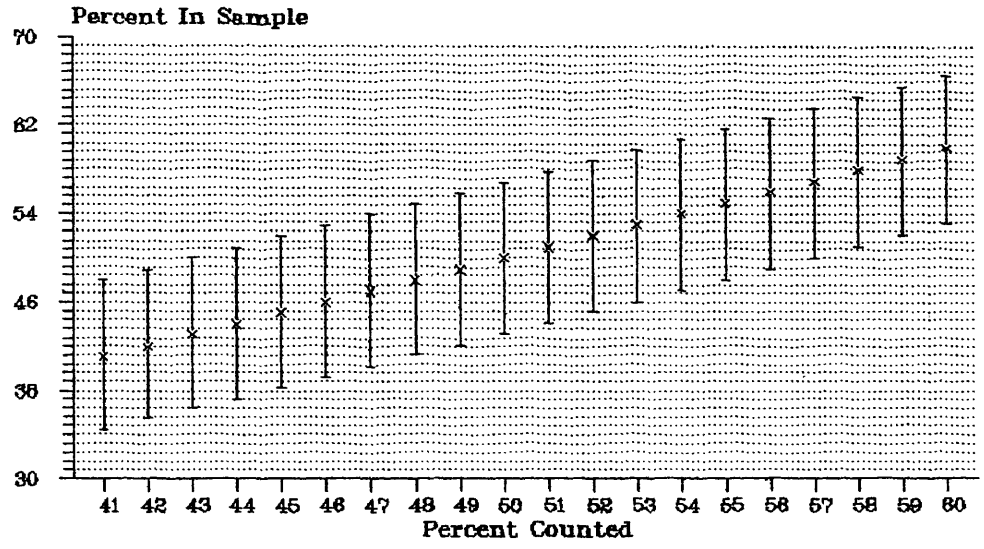

Text-Figure 14. 95% confidence intervals for counted percentages of 4% to 6%.



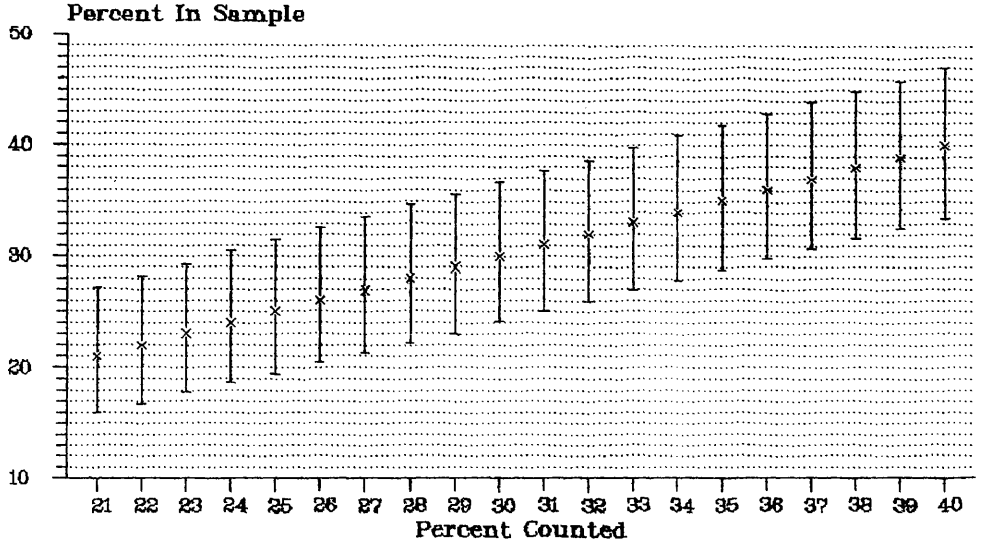

Text-Figure 15. 95% confidence intervals for counted percentages of 1%, 5% and 20%.



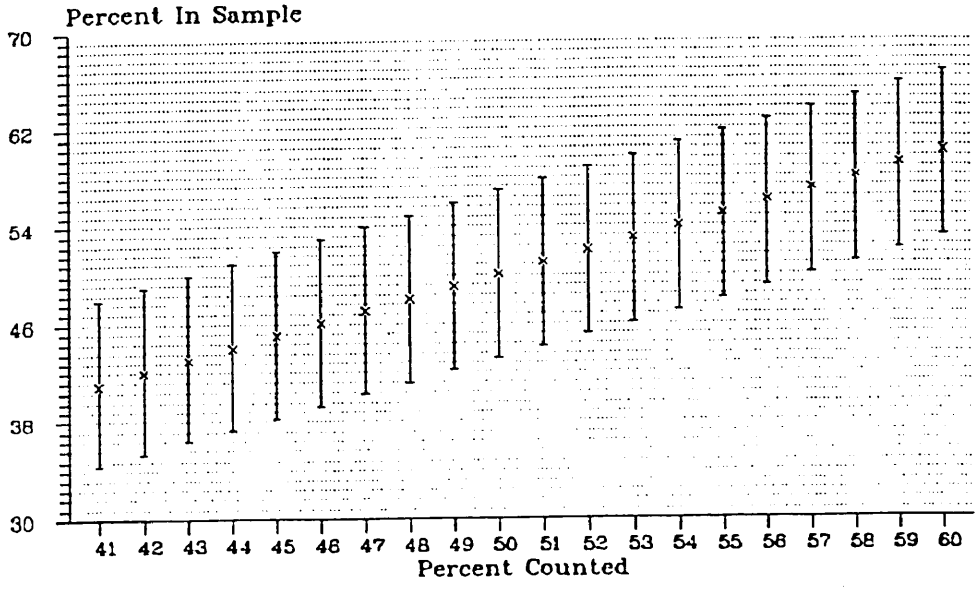

Text-Figure 16. 95% confidence intervals for counted percentage of 0%.




Text-Figure 17. 95% confidence intervals for 1% to 20% counting 200 grains.




Text-Figure 18. 95% confidence intervals for 21% to 40% counting 200 grains.




Text-Figure 19. 95% confidence intervals for 41% to 60% counting 200 grains.

# SYSTEMATIC PALEONTOLOGY

I based my identification and nomenclature on Frederiksen (1980a), and made no attempt to revise his taxonomy. In the following section, I have given not only standard taxon descriptions, but have also reviewed the available ecological information for each taxon.

## Genus Laevigatosporites Ibrahim 1933

### Laevigatosporites haardtii (Potonié & Venitz) Thomson & Pflug 1953

Sporites haardtii Potonié and Venitz 1934, p. 13, pl. 1, fig. 13.

Laevigtosporites haardtii (Potonié and Venitz) Thomson and Pflug, 1953, p. 59, pl. 3, figs. 27-38.

Laevigatosporites sp., Tschudy and Van Lonen, 1970, pl. 1, fig. 1.

**Description.** 25-70 μm. Outline beanshaped. Shape of the dehiscence concave to straight. Dehiscence thick, on both sides of the equator nearly or entirely reached.

**Affinity.** According to Frederiksen (1980a), Laevigatosporites may represent the modern families Aspidiaceae, Aspleniaceae, Blechnaceae, Gleicheniaceae, Lomariopsidaceae, Polypodiaceae, and Pteridaceae.

**Paleoenvironmental Notes.** Laevigatosporites sp. was the most important palynomorph in Maastrichtian deposits described by Kroeger (1985). It was most common in abandoned channel and flood basin marshes, but was also found in point bar and temporary pond and swale deposits. Farley and Dilcher (1986), in a study

of the Mid-Cretaceous Dakota formation, found L.ovatus to be more abundant in the "marshy lakeside" environment; floral differentiation among environments was not, however, strong. Laevigatosporites types were present in all three horizontal lignite samples tallied from the Eocene Gatuncillo Fm. of Panama by Graham (1985).

Graham (1987) indicated that he would have interpreted a high diversity and abundance of Laevigatosporites in the Miocene Uscari flora of Costa Rica as representative of local lowland marshes had other, Angiospermous, indicators been present. Nichols and Traverse (1971) reported a conspicuous abundance of Laevigatosporites in Paleocene Texas lignite samples characterized by palm pollen.

Farley (1990), in his study of the Early Eocene of Wyoming, found the greatest concentration of most spores, including Laevigatosporites, within the levee-crevasse splay environment. According to Farley, "...the abundance of Pteridiophyte spores reflects local stands of ferns whose rapid life style is well adapted to the unstable and damp substrate in the levee/crevasse splay environment.

Van der Hammen (1963) figured "Monolete spores" in his diagram from British Guiana. Almost all, he believed, were from the Polypodiaceae, which, he explained, "...occur frequently in freshwater swamps, but are also found under slightly brackish conditions." (p. 139)

The palynomorph flora of one Montana Paleocene coal described by Wilson and Webster (1946) contained 51.5% Laevigatosporites spp.

Extensive fern swamps were reported in the Orinoco Delta by Muller (1959). The distribution of Polypodiaceous types was highly dependant on proximity

to parent populations. In some areas these spores dominated. In two of his cores, however, the presence of Polypodium was explained as exotic spores blown in from Trinidad and Tobago.

**Occurrence.** Up to 32% in 12 lignites and the clastic sample at Lake Somerville.

**Range.** Frederiksen (1980a) indicates that L. haardtii spores have been found from the Cretaceous to the Recent.

## Genus Polypodiisporonites Potonié 1931

### Polypodiisporonites favus Potonié 1931

Polypodii(?)-sporonites favus Potonié, 1931, p. 556, fig. 3.
Verrucatosporites favus (Potonié) Thomson and Pflug, 1953, p. 60, pl. 3, figs. 52-55; pl. 4, figs. 1-4 [misidentified].
Polypodiisporites favus (Potonié) Potonié, 1956, p. 78.
Reticuloidosporites favus (Potonié) Krutzsch, 1959, p. 215, pl. 42, figs. 467-470.

**Description.** 30 to 80 μm. Resembling verrucate. "Warts" at most 2 μm high, their shape corresponding to their position on a hemisphere. Sulcus unbroken. (Translated from Thomson & Pflug)

**Affinity.** Assigned as a "probable" Polypodiaceae by Frederiksen (1980a).

**Paleoenvironmental Notes.** Kroeger (1985), studying a Maastrichtian sequence from South Dakota, reported a similar taxon, Polypodiidites Ross, also assigned to the Polypodiaceae. This taxon was rare and found only in flood basin marsh and temporary pond/swale environments.

In the Orinoco Delta, Muller (1959) reported a strong coincidence of Polypodiaceous spores in surface

samples and proximity of the mother plant. The heavily ornamented types, i.e. Polypodiisporonites type, settled most rapidly.

There are about 1000 living species in the Polypodiaceae and nearly all of them are epiphytes. Some, however, are not; Polypodium, for example, is terrestrial or ruprestral at the geographical and altitudinal limits of its range and epiphitic in the tropics. The genus can live from sea level to 4400 m., in a variety of moisture conditions. (Tryon and Tryon, 1982)

**Occurrence.** Up to 3% in 42 levels at San Miguel and up to 5% in 11 lignites and the clastic samples from Lake Somerville.

**Range.** Elsik (1968) found Polypodiisporonites afavus in the Paleocene Rockdale lignite and Frederiksen (1980a) found these grains from the Upper Claiborne to the Lower Vicksburg.

Genus Microfoveolatosporites Krutzsch 1959

Microfoveolatosporis pseudosentata Krutzsch 1959

Microfoveolatosporis pseudodentatus Krutzsch, 1959, p. 212, pl. 41, figs. 463-466.
Microfoveolatosporis cf. M. pseudodentatus Krutzsch, 1959. Engelhardt, 1964, p. 69-70, pl. 1, fig. 6.
Microfoveolatosporis cf. M. pseudodentatus Engelhardt, 1964. Tschudy and Van Lonen, 1970, pl. 1, fig. 3.
Microfoveolatosporis pseudodentata Krutszch, 1959. Frederiksen, 1980, p. 29, pl. 1, fig. 4.

**Description.** The only known form species of the form genus possesses one ca. 1/2-2 1/2 μm thick wall, which is distinctly two-layered. V=1.5-2/1. The

sculpture consists of a loose and sometimes delicate, netlike arrangement of roundish, foveolate cavities (z. T. of their small diameter) in the otherwise scabrate to smooth surface of the sporewall. The fovelolae are to approximately 1/2 of the outer/exterior layer deep. Sometimes, the outer wall layer shows beyond it a weak bar structure. The dehiscence is straight, ± long, r=about 3/4 to 4/5, sometimes delicate and weak. Outline and figure slender-oval. Size ca. 65-80 μm.

**Affinity.** Similar to Psilotum according to Kedves (1969) and to Schizaea pusilla Pursh, according to Engelhardt (1964).

**Paleoenvironmental Notes.** Psilotum grows on tree bases, logs, and hummocks in low wet woods, in the southeastern United States, as well as in the tropics. P. pusilla is a small, slender fern which lives in acid bogs in the northeastern part of North America (Mickel, 1979). Frederiksen (1980b) reported that Psilotum grows in humid subtropical, winter-dry tropical, and wet tropical regions.

**Occurrence.** Up to 6% in one lignite and the clastic sample at Lake Somerville.

**Range.** Found in the Paleocene Rockdale Lignite (Elsik, 1968)

## Genus Schizaea J.E. Smith

### Schizeaea tenuistriata (Pflanzl) Frederiksen 1980

Schizeaea tenuistriata (Pflanzl) Frederiksen, 1980a, p. 29, pl. 1, fig. 6.

Cicatricosisporites pseudodorogensis tenuistriatus Pflanzl, 1956, p. 239, pl. 16, fig. 5.

**Affinity.** According to Frederiksen (1981), similar to modern Schizaea laevigata Mett. and S. penicillata Kunth.

**Occurrence.** Found at 1% in one sample from Sequence B of San Miguel. Absent at Lake Somerville.

**Range.** Found from the Jackson (Moodys Branch) upwards in Mississippi (Frederiksen, 1980a).

## Genus Concavisporites J.E. Smith

### Concavisporites discites Pflug 1953

Concavisporites discites Pflug In: Thomson & Pflug, 1953, p. 49, pl. 1, fig. 24.

**Description.** 15-35 μm. End- and Extexospore with concave equatorial outline. Torus indistinct, with disclike formation. Y-ledges dispersing in a straight line. (Translated from Thomson and Pflug)

**Affinity.** Possibly Gleicheniaceae, according to Frederiksen (1980a).

**Occurrence.** Less than 1% in two samples at San Miguel, and absent at Lake Somerville.

**Range.** Frederiksen (1980a) found one specimen in the Jackson age Yazoo Clay of Mississippi.

## Genus Lygodium Schwarz

### Lygodium labratum Frederiksen 1980

Lygodium? labratum Frederiksen, 1973, p. 69, pl. 1, figs. 5-10.

Lygodium labratum Frederiksen, 1980a, p. 30, pl. 1, figs. 10-11.

**Description.** Size 29-42 μm, mean 35 μm, holotype 34 μm. Outline triangular; sides slightly convex to slightly concave. Trilete; sutures closed, labra 1.5-3 μm wide, rays straight, extending nearly full radius. Exine about 2 μm thick, sexine:nexine 2-3:1. Entire exine foveolate except labra; foveolae 0.5-1 μm in diameter, some of them anastomosing.

**Occurrence.** Less than 1% in one sample at San Miguel and absent at Lake Somerville.

**Range.** Frederiksen (1980a) found this taxon from the Upper Claiborne to the Lower Vicksburg of the Gulf Coast.

## Genus Lygodiumsporites Potonié 1956

### Lygodiumsporites adriennis (Potonié & Gelletich) Potonié 1956

Punctati-sporites adriennis Potonié and Gelletich, 1933, p. 521, pl. 2, figs. 14-15.
Lygodiumsporites adriennis (Potonié and Gelletich) Potonié, 1956, p. 19.
Leiotriletes adriennis (Potonié and Gelletich) Krutzsch, 1959, p. 57

**Description.** Outline-convex-triangular, strongly ringed; side flat to scabrate, 1.5-2 μm thick, V=2/1; all-around homogenous thickness; r=only 1/3 - 2/3, in points running out, size ca. 70 μm.

**Affinity.** Spores of L.adriennis are similar to those removed by Manchester and Zavada (1987) from remains of the extinct Lygodium Kaulfussi Heer. The fossils, from the Upper Eocene Bridger Formation, consist of attached fertile and sterile fronds. The spores are trilete, psilate, and 55-70 μm in diameter.

According to these authors, L. kaulfussi has been described from the Eocene of Alabama by Berry (1924). Similar spores were isolated from L. kaulfussi pinnules from Dorset, UK, by Chandler (1955). L. adriennis spores are common in Eocene Gulf Coast sediments. Frederiksen (1980a), citing the similarity to spores of A. aureum L., believed them to be produced by both Acrostichum, some species of which commonly occur in salt water today, and Lygodium. Citing Berry's identification of Acrostichum georgianum Berry leaves in the Claiborne and Jackson (Eocene) rocks of Georgia, Frederiksen stressed the resemblance to Acrostichum. Westgate and Gee (in press) found L. adriennis in association with Spinozonocolpites (thought to be synonymous with the mangrove Nypa) in Eocene sediments from Texas and consequently believed the affinity to be with brackish-water Acrostichum.

**Paleoenvironmental Notes.** The genus Lygodium contains Schizaceous ferns which, according to Manchester and Zavada (1987), are "...characterized by unusual leaves adapted for climbing. " (p. 392) Lygodium commonly lives along forest borders where it can get light. In tropical America, it may live in rain forests or more commonly, gallery forest, shrubby savannah or along borders of streams, from sea level to 1000 m. (Tryon and Tryon, 1982). Today, the genus Acrostichum is pantropical and contains ferns which inhabits a range of fresh to saltwater wetlands (Mickel, 1979).

**Occurrence.** Up to 2% in 18 samples from San Miguel and up to 1% in two samples at Lake Somerville.

**Range.** Dispersed spores attributed to Lygodium were present in Triassic sediments and macrofossils date from the Upper Cretaceous (Manchester and Zavada, 1987).

Found in Upper Claiborne to Lower Vicksburg of the Gulf Coast by Frederiksen (1980a).

## Genus Ctenopteris Blume

### Ctenopteris? elsikii (Frederiksen) Frederiksen 1980

Undulatisporites sp., Elsik 1968, p. 294, pl. 8, fig. 4; pl. 10, fig. 6.
Undulatisporites elsikii Frederiksen, 1973, p. 69-70, pl. 1, figs. 11-12, 18.
Ctenopteris? elsikii (Frederiksen) Frederiksen, 1980a, p. 31, pl. 2, fig. 5.

**Description.** Size 22-47 μm, mean 30 μm, holotype 32 μm. Outline triangular, with convex to slightly concave sides and narrowly rounded corners. Trilete; sutures closed; labra wavy, o.5-1 μm wide and about 3 μm high, extending nearly to the outline. Exine 1-1.5 μm thick, psilate or rarely infrapunctate, sometimes with one or two coarse folds.

**Affinity.** Frederiksen (1980a) believed this grain to be very similar to several species of modern Ctenopteris.

**Occurrence.** Less than 1% in one sample from San Miguel and absent at Lake Somerville.

**Range.** Elsik (1968) found this spore in the Paleocene Rockdale lignite and Frederiksen (1980a) found it in samples from the Upper Claiborne to the Lower Vicksburg of the Gulf Coast.

## Genus Granulatisporites Ibrahim 1933 emend. Potonié & Kremp 1954

### Granulatisporites luteticus (Krutzsch) Frederiksen 1980

Punctatisporites luteticus Krutzsch, 1959, p. 61-62, pl. 1, figs. 3-7.

Granulatisporites luteticus (Krutzsch) Frederiksen, 1980a, p. 31, pl. 2, fig. 13.

**Description.** Shape roundish-triangular, surface completely dense with incomplete equally size punctate-granulate bordered sculptural elements. Outline lightly wavy. Spore wall three layered, V=1/1/1, only about 1-1.5 μm thick, from there frequently secondarily declined. Y-mark distinct, radiating in a straight course, r=1/2-3/4. Immediately on the rays, the sculptural elements are mostly fused. Size about 50-70 μm.

**Affinity.** According to Frederiksen (1980a), similar to spores of Acrostichum aureum L.

**Paleoenvironmental Notes.** Acrostichum aureum is a pantropical fern occurring in this country in peninsular Florida. It inhabits freshwater swamps and brackish to saltwater marshes (Mickel, 1979).

**Occurrence.** Less than 1% in one sample from San Miguel and 1% in the clastic sample at Lake Somerville.

**Range.** Frederiksen (1980a) found only one specimen from the Jackson age Yazoo Clay of Mississippi.

Genus Cicatricosipories Potonié & Gelletich 1933 emend. Potonié 1966

Cicatricosisporites dorgensis Potonié and Gelletich 1933

Cicatricosisporites dorogensis Potonié and Gelletich, 1933, p. 522, pl. 1, figs 1-5.

**Description.** Trilete spores, amb triangular, sides straight to slightly convex, apices rounded, equatorial diameter 50-56 μm. Laesurae reach full radius. Exine

3.0 to 4.0 μm thick, sculpture cicatricose, muri and vallae 2.0 to 2.5 μm wide, parallel to the sides of the spore proximally and distally. Exine may be radially thickened and the ends of the angles unsculptured.

**Affinity.** Frederiksen (1980a) attributed Cicatricosisporites to the Schizacean genera Anemia or Mohria. Graham (1985) believed that Cicatricosisporites resembled Ceratopteris in the Parkiaceae. Chandler (1955) illustrated similar spores isolated from the Early Tertiary megafossil Anemia colwellensis Chandler.

**Paleoenvironmental Notes.** Cicatricosisporites spores probably conspecific with C. dorogensis were rare in a Maastrichtian deposit described from North Dakota by Kroeger (1985). The genus occurred only in point bar deposits. Farley and Dilcher (1986) found Cicatricosisporites spp. to be more common in "marshy lakeside" environments of the Middle Cretaceous Dakota Formation.

Graham (1985) reported the taxon as common (15%) in one horizontal lignite sample but absent in two others from the middle(?) to upper Eocene Gatuncillo Fm. of Panama.

The very similar Cicatricosisporites intersectus was found in abundance in the Late Eocene to Early Eocene Kitsalano Fm. of British Columbia by Hopkins (1967). He indicated that it was restricted to the coastal lowlands.

Ceratopteris is a genus of tropical water ferns. Two species occur in this country and inhabit mud and quiet water in southern Florida and Louisiana. Anemia inhabits limestone substrates from Florida and the Caribbean to the Edwards Plateau of Texas and southern Mexico (Mickel, 1979). It is a terrestrial species and in general a genus of open habitats and well drained

sites, with habitats from sea level to 3200 m. (Tryon and Tryon, 1982).

**Occurrence.** Up to 47% in 41 samples at San Miguel and to 59% in three lignite samples as well as in the clastic sample at Lake Somerville.

**Range.** Found in the Paleocene Rockdale Lignite by Elsik (1968) and in the Upper Claiborne to Lower Vicksburg by Frederiksen (1980a).

## Genus Selaginella Beauvois

### Selaginella perinata (Krutzsch et al.) Frederiksen 1980

Lusatisporis perinatus Krutzsch et al., 1963, p. 98, pl. 30, figs. 10-11.
Selaginella sinutus Martin and Rouse, 1966, p. 185-186, pl. 1, figs. 7-8.
Selaginella perinatus (Krutzsch et al.) Frederiksen, 1980a, p. 33, pl. 3, figs. 14-15.

**Description.** Spore outline circular or only slightly triangular. Perispore decidedly coarsely granular, finely wrinkled, and extending from 2 to 5 μm beyond the limits of the endospore. Thickness of perispore ca. 1 μm. The laesurae of the trilete mark are wavy, and the margo is much wrinkled, thus giving the appearance of a sinuous ribbon. Small radial folds on the perispore occur on the interradials. Range of diameter: 28-48 μm. (Martin and Rouse, 1966)

**Affinity.** Martin and Rouse (1966) report that the spores are virtually identical to the extant species Selaginella wallacei and S. oregona.

**Paleoenvironmental Notes.** Most species of the fern ally Selaginella are found in tropical regions, but the genus is also found as far north as Alaska. Modern

habitats range from wetland to dry pine woodlands and dunes (Mickel, 1979).

**Occurrence.** Less than 1% in one sample from San Miguel and absent at Lake Somerville

**Range.** Elsik (1968) found this species in the Paleocene Rockdale lignite. Frederiksen (1980a) found this species in samples ranging from the Upper Claiborne to Lower Vicksburg of the Gulf Coast.

Genus Sphagnum (Dill.) Ehrh.

Sphagnum stereoides (Potonié and Venitz) Martin and Rouse 1966

Sporites stereoides Potonié and Venitz, 1934, p. 11-12, pl. 1, figs. 4-5.
Stereisporites stereoides (Potonié and Venitz) Thomson and Pflug 1953, p. 53, pl. 1, figs. 64-73.
Sphagnumsporites steroides (Potonié and Venitz) Potonié, 1956, p. 17.
Sphagnum steroides (Potonié and Venitz) Martin and Rouse, 1966, p. 184, pl. 1, fig. 3.

**Description.** 15 to 30 μm. Exospore under 2 μm thick. Y-border reaching the equator.

**Paleoenvironmental Notes.** Nichols and Traverse (1971), in their palynological study of Late Paleocene Texas lignites, found Sphagnum percentages of a few to 10% indicative of a fluvial swamp environment.

Modern Sphagnum, or peat moss, lives in wetlands, most often in peat bogs. It creates an acid environment for itself and other plants. (Crum, 1976)

**Occurrence.** Less than 1% in two samples from San Miguel and 1% in one lignite sample from Lake Somerville.

**Range.** This species was found by Frederiksen (1981) from the Oligocene Vicksburg Group. Elsik (1968) found it in the Paleocene Rockdale Lignite.

Genus Cupressacites Bolkhovitina 1956

Cupressacites hiatipites (Wodehouse) Krutzsch 1971

Taxodium hiatipites Wodehouse, 1933, p. 493, fig. 17.
Taxodiaceaepollenites hiatus (R. Potonié, 1931) Kremp, 1949 [misidentified]. Engelhardt, 1964, p. 71, pl.1, fig. 10.
Inaperturopollenites cf. I. hiatus (R. Potonié) Thomson and Pflug, 1953. Tschudy and Van Lonen, 1970, pl. 2, figs. 5-6.
Cupressacites hiatipites (Wodehouse) Krutzsch, 1971, p. 41.

**Description.** 25-50 μm. Outline spherical, less often decayed. Swollen and burst open, thereby a characteristic bill-like aperture (Hiatus). Exine over 1 μm thick, psilate to scabrate, distinctly two-layered. Sometimes one can discern an indistinct ligula and an exit pore.

**Affinity.** Probably the Taxodiaceous genera Taxodium or Glyptostrobus, according to Frederiksen (1980a).

**Paleoenvironmental Notes.** C. hiatipites pollen is extremely rare in Eocene Gulf Coast lignites (Elsik, 1978; Frederiksen, 1981). The taxon is present in larger percentages in Late Paleocene sediments (Elsik, 1978; Gennett, unpublished data from Louisiana; Kroeger, 1985). Elsik mentioned that "Taxodium is abundant in many marine and non-marine clastic sediments of Paleocene-Lower Eocene [sic] of the Gulf Coast. (p. 29)"

and suggested that distribution is tied to water transport.

Presently distributed along the Atlantic and Gulf Coastal Plains and in the Mississippi Valley, Taxodium (baldcypress) most often grows in permanent swamps (Harrar and Harrar, 1962). Coverage of T. distichum ranges up to 40% in the Mississippi delta and to 60% in Florida; Taxodium comprises 60% of arboreal pollen in some parts of the Mississippi delta (Delcourt et al., 1984). Most Cupressaceae species shed huge amounts of wind dispersed pollen.

**Occurrence.** Less than 1% in 5 samples from San Miguel and 1% in three lignite samples and the clastic sample at Lake Somerville.

**Range.** Frederiksen (1980a) found this taxon infrequently to occasionally in the Upper Claiborne to Lower Vicksburg of the Gulf Coast; Elsik (1968) found more abundant grains in the Paleocene Rockdale lignite.

## Bisaccate Pollen Group

Because of present uncertainties in the classification of Tertiary bisaccate pollen (T. Timmcke, oral commun., 1989), I followed Kroeger (1985) and combined the few grains into a descriptive group.

**Affinity.** Frederiksen (1980a) classified all bisaccate pollen present in his Gulf Coast Eocene as members of the Pinaceae. Individuals present in the San Miguel samples resemble members of the modern genera Picea or Pinus as illustrated by McAndrews et al (1978).

**Paleoenvironmental Notes.** Species of the Pinaceae were reported as infrequent to rare by Frederiksen (1980a) in Gulf Coast Jackson Group samples. Potter

reported only rare occurrences in the Tennessee Claiborne and Kroeger (1985) described the group as uncommon in the Paleocene of South Dakota. On the other hand, Mancini (1981) listed Pinaceae pollen as characteristic of Alabama marine shales interbedded with Middle Paleocene Naheola lignites. An increasingly coniferous Cordilleran flora (Leopold and McGinitie, 1972) may have provided a long distance source for bisaccates; Bartley (1967) for example, reported a site in Quebec almost 500 km from a pine source receiving 24% Pinus pollen. Dilcher (1973) noted, for the Middle Eocene of Tennessee, "The Appalachian highland is often used to explain the presence of temperate forms in the Mississippi embayment and may be a valid explanation for the presence of some pollen such as Pinus which is not yet reported as a megafossil and might have come from upland plants rather distant from areas of deposition." (p. 56)

**Occurrence.** Less than 1% in one sample from San Miguel and 1% in one lignite at Lake Somerville.

## Genus Ephedra Linnaeus

### Ephedra claricristata Shakhmundes 1965

Ephedra claricristata Shakhmundes, 1965, p. 226-227, fig. 10.

Ephedra eocenica Shakhmundes, 1965, p. 219-220, figs. 2-3.

Ephedripites (Distachyapites) tertiarius Krutzsch, 1970, p. 156, 158, fig. 20; pl. 44, figs. 1-21.

Gnetaceaepollenites eocenipites (Wodehouse, 1933) R. Potonié, 1958 [misidentified]. Engelhardt, 1964, p. 70, pl. 1, fig. 8.

Ephedra sp. (distachya-type), Fairchild and Elsik, 1969, p. 83 pl. 37, fig. 2.

Ephedra sp. (type A of Steeves and Barghoorn 1959), Tschudy and Van Lonen, 1970, pl. 1, fig. 1.

Ephedra type A of Stevens and Barghoorn, 1959. Tschudy, 1973, p. B17, pl. 4, figs. 22-23.

**Occurrence.** Less than 1% in 9 samples at San Miguel and absent at Lake Somerville.

**Range.** Found by Frederiksen (1980a) in the Upper Claiborne to Lower Jackson.

Ephedra hungarica (Nagy) Frederiksen 1980

Ephedripites hungaricus Nagy, 1963, p. 278, figs. 1-3, 12A

Ephedra hungarica (Nagy) Frederiksen, 1980a, p. 37, pl. 7, fig. 4.

**Description.** Pollen grain perprolate (47 X 19 μm) tapering towards the supposed poles. Walls thin, provided with about 10 to 11 ridges. Ridges narrowing and converging towards the poles, 1 to 1.5 μm wide. Grooves between the ridges not wider than 0.5 μm. In the center of the ridges is a dark stripe. At lower focus, a white stripe (about 0.5 μm wide) becomes visible between the dark stripes on both margins of the ridges. Towards the ends of the pollen grain the ridges converge and appear to be somewhat twisted.

**Affinity.** Ephedra is an extant plant. Specimens from the San Miguel lignites are similar to modern grains pictured in McAndrews et al. (1978) and in the TAMU pollen reference collection.

**Paleoenvironmental Notes.** Extant forms are common in arid climates. Gray (1960), Hopkins (1967) and Frederiksen (1985) believed that Ephedra may have had a

broader ecological range in the Eocene than at present. These authors have suggested that, because Ephedra has been found mostly in brackish or marine sediments, that it may have part of the Eocene beach flora. Hopkins and Sweet (1976) found Ephedra pollen in black shale and coal in the Eocene/ Oligocene Kishenehn Formation of southeastern British Columbia. They suggested that the plants were growing in dry locations at the lee of mountains. Frederiksen (1981) suggested that Ephedra was part of the shrub layer because of its appearance in low quantities in many samples. This, according to Frederiksen indicated abundant, widespread plants with low pollen productivity.

Ephedra has been found in Quaternary cores from Lake Superior, making up an average of .03% of the pre-1890 pollen sum. Janssen (1967) also pictured Ephedra in his study of pollen in Quaternary sediments at Stevens Pond, Minnesota. Ephedra is not included in Lakela's (1965) Flora of Northeastern Minnesota, nor is it described in Gleason and Cronquist's (1963) flora of the eastern United States. Long distance aerial transport is inferred for these sites.

**Occurrence.** Less than 1% in two samples from San Miguel and absent at Lake Somerville.

**Range.** Frederiksen (1988) reported Ephedra hungarica from the lower part of the Lisbon Formation (Middle Eocene) into the Oligocene. Ephedra first appeared in the Gulf Coast in the Claiborne Formation (Fairchild and Elsik, 1969); it was established in the continental interior by the end of the Cretaceous (Frederiksen, 1985).

Genus Graminidites Cookson 1947

Graminidites gramineoides (Meyer) Krutzsch 1970

Monoporopollenites gramineoides Meyer, 1956, p. 111, pl. 4, fig. 29.
Graminidites gramineoides (Meyer) Krutzsch, 1970, p. 15.
Graminidites spp. Tschudy, 1973, p. B17, pl. 4, figs. 34-35.

**Description.** Mean of long and short dimensions, 19-36 μm, mean 30 μm. Exine, 0.3-0.5 μm thick, considerably folded, usually crushed to an oval shape; nearly psilate but fairly punctate, granulate or verrucate; outline nearly smooth. Diameter of pore 1.7-2.5 μm; width of annulus 2.5-3 μm.

**Affinity.** Gramineae, according to Frederiksen (1980a)

**Occurrence.** Less than 2% in two levels from San Miguel and absent from Lake Somerville.

**Range.** Frederiksen (1988) reported first occurrences of Graminidites just below the base of the Gosport Sand.

Genus Milfordia Erdtman 1960 emend. Krutzsch 1970

Milfordia sp.

Milfordia Erdtman, 1960, p. 46.
Monulicipollenites Fairchild in Stover et al., 1966, p. 2-3.
Restioniidites Elsik, 1968, p. 313.
Milfordia Erdtman emend. Krutzsch, 1970, p. 18.

**Affinity.** Restoniaceae, Flagellariaceae, or Centolepidaceae, according to Frederiksen (1980a).

**Paleoenvironmental Notes.** According to Frederiksen (1981), "Milfordia pollen is very abundant in some Eocene and lower Oligocene deposits in Europe, and the

Centrolepidaceae-Flagellariaceae-Restoniaceae may have been important marsh plants during this time interval...However... the producers of this pollen do not seem to have been important in the peat-forming swamps. (p. 531-532)" Milfordia was rare in the Gulf Coast coals studied by that author.

**Occurrence.** Up to 2% in four levels from San Miguel and absent from Lake Somerville.

**Range.** The genus was reported from the Claiborne Group by Fairchild and Elsik (1969) and from the Jackson Group by Frederiksen (1980a).

Genus Aglaoreida Erdtman 1960 emend. Fowler, 1971

**Description.** Pollen grains monoporate, bilaterally symmetrical with the poriferous or non-poriferous usually flattened. Spheroidal to elliptical, the longest axis of the pore usually at angles to the longest axis of the grain. Pore margin uneven with thickened endexine. Exine reticulate with coarsely and finely reticulate areas clearly demarcated in a distinctive pattern on the surface of the grain.

**Affinity.** Frederiksen (1980a) believed that this genus was Monocotyledonous "...possibly Ruppiaceae or Potomogetonaceae according to Machin (1971, p. 856)." (p. 38.)

**Paleoenvironmental Notes.** Fowler (1971) believed these pollen grains to have come from brackish to fresh water hydrophytes. The genus is rare in samples examined by Frederiksen (1980a, 1981).

**Occurrence.** Less than 1% in one sample from San Miguel and absent from Lake Somerville.

**Range.** Found from Upper Middle Eocene to Oligocene on the Gulf Coast (Frederiksen, 1980a).

Genus Momipites Wodehouse 1933 emend. Nichols, 1973

**Description.** Grains spheroidal or oblately flattened and somewhat triangular in outline. Pores three on the equator with their apertures broadly elliptical and meridionally oriented, only slightly protruding above the surface, and with the exine immediately surrounding them slightly thickened corresponding to the Corylus pattern. Texture smooth.

**Affinity.** As can be inferred from the synonym Engelhardtia, Momipites is very similar to pollen of the modern Juglandaceous genus Engelhardtia. Momipites, the form-genus, was isolated by Crepet et al. (1975, 1980) from fossil catkins similar to the present-day Engelhardtia-Oromunnea-Alfaroa complex. According to Nichols (1973), morphological differentiation between Alfaroa and Engelhardtia pollen is not possible, and some fossil grains are not comparable to either genus, resembling more closely the other Juglandaceous genera. Leaves from the Claiborne Group of Tennessee, more similar to Alfaroa and Oreomunnea than Engelhardia, were described by Dilcher and Manchester (1986) and designated as Oreoroa claibornensis. Manchester (1983) also described fossil wood from the tribe Engelhardieae (undifferentiated) occurring in the Yegua formation. "Momipites...is abundant in the same formation," he said.

The name Momipites was originally given to the genus by Wodehouse (1933) and signified a resemblance to Momisia, a member of the Ulmaceae (elm family).

**Paleoenvironmental Notes.** According to Frederiksen (1985), "...during the past 30,000 years in the highlands of Papua, New Guinea, the relative frequency

of Engelhardtia has fluctuated independently of...other genera with which it is now associated...even during short time periods Engelhardtia seems to change its associates as climatic and ecological conditions change."

Momipites has, in fact, been correlated with changing environmental conditions. Pocknall (1987) used the ratio between Momipites spp. and spp. to define biozones in the Paleocene and Late Eocene of Wyoming. He found that the change between assemblages dominated by the two genera coincided with sedimentological change between fluvial and fluvial lacustrine due to increased tectonism. The increase in relief due to tectonism also initiated a more seasonal climatic regime.

Thoughts on Momipites are numerous. Nichols (1971) found that in the Paleocene of Texas, one species of "Engelhardia" was more common in clays and another in lignites. Traverse (1955) discovered that Momipites in the Oligocene Brandon Lignite sequence was more common in lignitic sand. Graham and Jarzen (1969) described an Oligocene sequence in Puerto Rico in which Momipites-rich clastics alternate with Rhizophora-rich peat. In his study of the Tennessee Claiborne, Potter (1976) noted that both important Momipites species (probably equivalent to M. microfoveolatus and M. coryloides) were common both in clastic sediments and at the base of his lignite seam. Momipites grains were rare in most of the lignite. He believed this taxon to be part of the "Background" rain.

Some authors have used Momipites pollen as a marsh indicator. Elsik (1986) suggested that this taxon was blown into a Yegua-Jackson marsh to form the Momipites dominated assemblage in Zapata county. Elsik (1978) assigned a "regional pollen" status to Momipites spp.

because modern Engelhardia grows in upland areas, and because Manning lignites exhibit a low diversity of arboreal pollen. Mukhopadhyay (1989) well used Momipites as a marsh indicator in cursory examinations of San Miguel and Lake Somerville lignites. Conversely, Elsik (1978) found abundant Momipites in a fluvial Yegua Fm. lignite from Madison Co., TX.

In his study of clays and brown coals from the Eocene of Germany, Pflug (1957) grouped Momipites as a genus more likely to be abundant in clays and inferred that it came from lakeshore vegetation. Kvacek (1972), reviewing the occurrence of Engelhardia leaf fossils in Europe, emphasized that, because it is not represented in the Glyptostrobus-Taxodium-Alnus-Nyssa community of the Miocene brown coal swamp forest, Engelhardia was not adapted to lowland swampy conditions during the Tertiary. He believed the fossil Engelhardia of Europe to be "...a typical subtropical component with a great demand on high atmospheric humidity." (p. 30)

In addition to pollen, peltate leaf hairs from the Engelhardieae appear occasionally in palynomorph preparations (Elsik and Dilcher, 1974).

Modern forms are restricted to Asia, where they may live in swampy areas in buttressed form, and the highlands of Central America, where they require summer rainfall, constant high humidity, warm dry winters and an almost unseasonal climate (Leopold and McGintie, 1972). Engelhardtia and Alfaroa both grow today in Costa Rica. Holderidge et al (1971) recorded E. mexicana as a canopy tree, and the two species of Alfaroa as an intermediate size tree. Life zones included wet tropical, moist tropical, premontain wet, and premontane rain forest. Fredericksen (1980c) listed the climatic requirements of the Engelhardtia-Oromunnea-

Alfaroa complex as: 1) humid subtropical with precipitation in all seasons and more than three cm rain in the driest month in summer, or 2) winter dry tropical, with more than two months dry, or wet tropical, with ten to twelve months wet.

Flenley (1979) described Engelhardia as basically a montane genus, with some species growing in lowland forests. One species, E. spicata, is found in mountain swamps.

**Range.** A common Tertiary palynomorph, Momipites is common throughout the Late Eocene and Oligocene of the United States; Nichols (1973) gave the range of the M. coryloides group, which contains both M. coryloides and M. microfoveolatus, as Paleocene to Miocene. The genus persisted into the Miocene in Idaho, and Alaska, but not the Gulf Coast.

## Momipites coryloides Wodehouse 1933

Momipites coryloides Wodehouse, 1933, p. 511, fig. 43.
Engelhardtia sp., Fairchild and Elsik, 1969, p. 83, pl. 37, figs. 8-9.
?Momipites sp., Tschudy and Van Loenen, 1970, pl. 2, fig. 15.
Triatriopollenites sp., Tschudy and Van Loenen, 1970, pl. 3, figs. 1-2.
Triatriopollenites sp. of the T. coryphaeus type (20-30 μm.), Tschudy, 1973, p. B16, pl. 4, figs. 12-13.

**Description.** Oblately flattened and triangular in outline, 21-33.1 μm in diameter.

**Affinity.** Crepet et al. (1975) removed similar pollen, described as "...triporate, occasionally tetraporate, very finely scabrate exine, mean equatorial diameter is 19.6 μm", from a Claiborne-age macrofossil,

Eokachyra. Perianth parts, peltate scales, and stomata referable to the extant Juglandaceous Engelhardtia-Oromunnea-Alfaroa complex were present as macrofossils.

**Paleoenvironmental Notes.** Both the floral and pollen structure of Eokachyra suggested to Crepet et al. (1975) that pollination was anemophilous. These characteristics included small perianth, exposed anthers, and smooth pollen grains. Pollination mechanisms in the extant E-O-A complex are not well known, but according to these authors the floral structure also suggests anemophily.

**Occurrence.** Present in all samples from 1 to 69% from San Miguel and Lake Somerville, at levels between 2 and 69%.

**Range.** Frederiksen (1980a) gives the range of M. coryloides in South Carolina as Late Paleocene to Upper Eocene, and for the Gulf Coast as Latest Paleocene to Lowest Oligocene.

Momipites microfoveolatus (Stanley) Nichols 1973

Engelhardtioidites cf. E. microcoryphaeus (R. Potonié, 1931) Potonié, Thomson, and Thiergart, 1950.
Engelhardtia microfoveolata Stanley, 1965, p. 300-301, pl. 45, figs. 8-13.
Triatriopollenites sp. of the T. coryphaeus type (13μm-18μm), Tschudy, 1973, p. B16, pl. 4, figs. 1-3.
Mompites microfovveolatus (Stanley) Nichols, 1973, p. 107.

**Description.** Oblate triporate pollen grains, outline in polar view triangular with straight to slightly convex sides and rounded apexes; equatorial diameter 15-22 μm. Endexine about 0.3 μm thick; ektexine thickness on the order of 0.6 μm making a total

exine thickness of about 1 μm. Sculpture a fine punctation with lumina approximately 0.3 μm wide. Pores meridionally elongated; dimensions 1 X 1.5 μm. Some specimens have arclike area that surrounds the pore region; this feature does not appear to be caused by the thickening of the exine but rather appears to be the result of more stain being accepted in this arclike region due perhaps to differences in exine chemistry.

**Affinity.** Pollen grains similar to but not formally identified as M. microfoveolatus were removed by Crepet et al. (1980) from a Juglandaceous catkin, Eoengelhardtia, preserved in the Claiborne Formation of Tennessee. They described these grains as small in size, averaging 14.8 μm in diameter, straight sided and triangular. Because of the floral and pollen morphologies, as well as the presence of large peltate scales, the authors believed this microfossil taxon to be closely allied with the modern Engelhardia-Oromunnea-Alfaroa complex. They further suggested that the genus, partially because of the small size of the pollen, was related to the Old World section Psilocarpeae.

**Range.** Frederiksen (1980a) gave the range for M. microfoveolatus as Cretaceous through Jackson in South Carolina and Uppermost Paleocene to Jackson on the Gulf Coast. Muller (1981) listed worldwide range of the M. fragilis type, including M. microfoveolatus, as Lower Campanian up to the Recent.

**Occurrence.** To 13% in 83 samples from San Miguel and in quantities between 1% and 11%, in all samples from Lake Somerville.

## Genus Platycarya Siebold & Zuccarini

### Platycarya sp.

Triatriopollenites cf. T. coryphaeus (R. Potonié, 1931) Thomson and Pflug, 1953. Engelhardt 1964a, p. 78, pl. 4, fig. 47.

Platycarya spp. Tschudy 1973, p. B14, pl. 2, figs. 30-31.

**Description.** 10 to 25 μm, rarely somewhat larger. Exine smooth to scabrate, rigid, only with insignificant secondary folds. Contour convex-triangular. Pores never prominent. Exine cross section ribbon shaped, on all places equally thick. Ektexine always over 3X thicker than the endexine. Large atrium without intrapunctate structure. The Early Tertiary representatives sometimes appear endoplicate. (Translated from Thomson and Pflug)

**Affinity.** Elsik and Dilcher (1974) commented that the exines of their Platycarya grains are folded and thinned or split in a manner similar to extant Platycarya. According to Nichols (1973), "Fossil pollen exhibiting the true Platycarya group morphology can be assigned to the modern genus." (p. 105) Wing and Hickey (1984) showed that high Platycarya pollen percentages coincided with an abundance of Platycarya macrofossils in the sediment record at their site in Wyoming. They also figured Platycara pollen removed from anthers of staminate inflorescences of P. americana obtained from the Golden Valley Fm.

**Paleoenvironmental Notes.** Frederiksen (1985) summarized occurrences of Platycarya in the Early Tertiary and concluded that "...Platycara (or a close relative)..." may have lived near the shores of tropical seas... and quite possibly even in peat swamps." (p. 12). Other authors, transporting modern ecological tolerances back into time, attributed very high percentages in Tertiary lignite and lignitic detritus to

long distance transport, assuming that Platycarya lived on dry hilly substrates (Gruas-Cavagnetto, 1976; Auffret and Grus-Cavagnetto, 1975). Wing and Hickey (1984), taking into account the abundance of Platycarya megafossils in the uppermost levels of their oxbow lake infill as well as modern ecological information, typified Early Tertiary Platycara as "...small, probably shrubby trees that rapidly colonized open or unstable ground, were fast growing and maturing plants...and may have formed thickets of dense, almost monospecific growth (p. 407)."

**Occurrence.** In values to 2% in three samples from San Miguel and absent from Lake Somerville.

**Range.** Platycarya appeared in the earliest Eocene and is one of the characteristic indicators of the Early Eocene throughout most of the Northern Hemisphere (Wolfe, 1973). Frederiksen (1980a) noted only one probable occurrence from the Upper Middle Eocene of Mississippi. Leopold and McGinitie (1972) citing Tschudy (1973) reported that Platycarya's last appearance in the Mississippi Embayment was in the Lower Jackson Group, "...just before a Late Eocene cool period. (p. 179)." Fairchild and Elsik (1969) noted that Platycarya is common in Claiborne sections.

## Genus Carya Nuttall

### Carya veripites Wilson & Webster 1946

Carya veripites Wilson and Webster 1946, p. 276, fig. 14.

Caryapollenites cf. C. simplex (R. Potonié, 1931) Raatz, 1937. Engelhardt, 1964, p. 78, pl. 5, fig. 51.

Carya sp. or Caryapollenites sp. of C. simplex (Potonié) Raatz 1937, Tshudy and Van Loenen, 1970, pl. 3, fig. 11.

Carya sp. or Caryapollenites sp., Tschudy and Van Loenen, 1970, pl. 3, figs. 12a-b.

**Description.** Grains circular to slightly triangular in equatorial view, oblately flattened; diameter 27-33 μm; germ pores three, round to broadly elliptical in shape, 3-4.5 μm long, all in one hemisphere, placed 3-4.5 μm from the equator; exine smooth, translucent, approximately 1.5 μm thick near equator; polar areas apparently thinner and sometimes corroded or broken, resulting in an irregularly modified area near the center of the grain.

**Affinity.** Carya (modern hickory).

**Paleoenvironmental Notes.** Frederiksen (1980a) reported these grains as infrequent to occasional in his Late Eocene samples. In the Oligocene Brandon lignites of Vermont, Carya was most abundant in the clastic samples beneath the lignite (Traverse, 1955).

There are 20 species of hickory now growing in the United States. Most species prefer the uplands, but one, Carya aquatica (water hickory) lives in the deep swamps of the southern coastal plains. (Harrar and Harrar, 1962) Modern-day Carya is wind pollinated, but according to Lewis et al. (1983), is large and not well adapted to anemophily.

**Occurrence.** Less than 1% in 19 samples from San Miguel and up to 2% in seven lignites from Lake Somerville.

## Genus Planera J. F. Gmelin

### Planera thompsoniana Traverse 1955

Planera thomsoniana Traverse, 1955, p. 52, fig. 10 (53)
Ulmus cf. Zelkova Gray, 1960, table 1 and fig. 1f.
Ulmipollenites cf. U. undulosus Wolff, 1934. Engelhardt, 1964, p. 79, pl. 5, fig. 58.
Ulmipollis sp., Tschudy and Van Lonen, 1970, pl. 3, figs. 16, 22, 25.

**Description.** Ca. 5-stephanoporate pollen grain with the pores strictly equatorial or nearly so, the pores with thickened rims, both of ektexine (annuli) and endexine (costae). Both hemispheres may have linear thickening in the exine, that is, arci. The sculpture is a low reticulum with wide muri. Sculpture much less pronounced in one hemisphere, this hemisphere often collapsed into the grain. Size: ca. 35 μm by 41 μm (Much flattened, disc-shaped.) Thickness of exine: ca. 2 μm.

**Affinity.** Frederiksen (1980a) noticed that these grains have arci which are typical of Planera and Zelkova.

**Occurrence.** Found at 1% from one sample from Sequence E of the San Miguel lignite. Absent from Lake Somerville.

**Range.** Found from the Upper Claiborne to Lower Vicksburg by Frederiksen (1980a).

## Genus Pterocarya Kunth

### Pterocarya stellata (Potonié) Martin and Rouse 1966

Pollenites stellatus Potonié, 1931, p. 4, fig. 20.
Polyporopollenites stellatus (Potonié) Thomson and Pflug, 1953, 91-92, pl. 10, figs. 85-94.
Polyatrio-pollenites stellatus (Potonié) Pflug, 1953, p. 115, p. 24, fig. 47.

Pterocarya vermontensis Traverse, 1955, p. 45, fig. 9 (29).

Pterocaryapollenites stellatus (Potonié) Potonié, 1960, p. 132.

Pterocaryapollenites vermontensis (Traverse) Potonié, 1960, p. 132.

Pterocarya stellatus Martin and Rouse, 1966, p. 196, pl. 8, figs. 79-80.

Multiporopollenites sp., Tschudy and Van Lonen, 1970, pl. 3, fig. 33.

**Description.** Ca. 6-stephanoporate pollen grain, with the pores showing typical Juglandaceous tendency to have the pores more or less displaced off the equator into one hemisphere. Pores with thickened rims, that is, annuli. Exine sculpturing scabrate. Size: ca. 37 μm. Thickness of exine: ca. 1.6 μm.

**Affinity.** Pterocarya

**Paleoenvironmental Notes.** Frederiksen (1980a) found this taxon infrequently in his Jackson Group sediments. Leopold and McGinitie (1972) reported Pterocarya as "...common in the southeast and midcontinent. (p. 182)" by the Eocene. They noted that the modern Pterocarya "...requires summer rainfall, but can tolerate low annual rainfall and subhumid conditions. (p. 182)"

**Occurrence.** Less than 1% in one sample from San Miguel and absent from Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg from the Gulf Coast (Frederiksen, 1980a).

## Genus Celtis Linnaeus 1980

### Celtis tschudyi (Elsik) Frederiksen

Pollenites anulus (Potonié, 1931) Potonié and Venitz, 1934 [misidentified]. Engelhardt, 1934, 1964a, p. 79, pl. 5, figs. 60-61.

Juglanspollenites sp., Tschudy and Van Loenen, 1970, pl. 3, figs. 29-30.

Multiporopollenites spp. Tschudy, 1973, p. B15, pl.3, figs. 20-22.

Nothofagus tschudyi Elsik, 1974, p. 290, 292-294, pl. 1, figs. 1-5; pl. 2, figs. 1-9.

Cf. Nothofagus Dombeyi Type. Elsik, 1974b, p. 2, fig. 44.

Celtis tschudyi (Elsik) Frederiksen, 1980a, p. 43, pl. 8, figs. 23-25.

**Taxonomic notes.** C tschudyii was later placed in the larger C. tschudyi group by Frederiksen (1988). The group encompasses a continuum of four species. He felt that "...the species seem to intergrade so much that they are impossible to differentiate consistently." (p. 51)

**Affinity.** Thought by Frederiksen (1980a) to be equivalent to modern Celtis.

**Paleoenvironmental Notes.** Grains of Triporopollenites pliktosus Anderson 1960, probably equivalent to Celtis, were more common in the clay layer of Potter (1976) from the Claiborne of Tennessee.

Celtis laevigata (Texas sugarberry) is an common component of sweetgum-oak floodplains in parts of the Texas Big Thicket (Ajilvsgi, 1979). Flenley (1979) says of the occurrence of Celtis in the East African Quaternary, "...common in moist and dry lowland forests and its pollen exhibits very high relative export. Abundance of this pollen type therefore indicates forest in the lowlands, but not necessarily near the pollen site." (p. 134)

**Occurrence.** Less than 1% in one sample from San Miguel and less than 1% in one lignite and the clastic sample from Lake Somerville.

**Range.** Frederiksen (1988) gives the range of the triporate members of the C. tschudyi "group" as Middle Upper Sabinian to Upper Claiborne.

Genus Malvacipollis Harris 1965 emend. Krutzsch 1966

Malvacipollis tschudyi (Frederiksen) Frederiksen 1980

?Aff. Nothofagus sp., Tshudy and Van Loenen, 1970, pl. 3, figs. 23, 27-28.

Echiperiporites spp. Tschudy, 1973, p. B15, pl. 3. figs. 13-14.

Echiperiporites tschudyi Frederiksen, 1973, p. 75, 78, pl. 2, figs. 19-22.

Malvacipollis tschudyi Frederiksen, 1980a, p. 44, pl. 8, fig. 27.

**Description.** Size 28-29 μm, mean 33 μm, holotype 35 μm. Originally spheroidal, outline round. Exine 1.5 μm thick, sexine:nexine 4:1; tegillate; ectosexine and endosexine equally thick. Sexine granulate and conate, the coni about 1 μm in diameter at the base, tapering evenly toward the point, and 1-2 μm high. Pores arranged only around the equator, although this is not immediately obvious because the grains were spheroidal and became compressed in many different orientations. Pores may be somewhat difficult to see; the grains are apparently 3- to 8-porate; holotype has 6 or 7 pores. Pores 1-2, μm in diameter; slight lanbra and (or) slight annuli present; vestibula 1-1.5μm deep; nexine thickened (to about 0.5 μm) under vestibula; no endospores evident.

**Affinity.** Frederiksen (1980a) originally hypothesized a Malvaceous sporophyte for M. tschudyi, but later (Frederiksen, 1988) noted that, because the sexine is not thickened under the spines, M. tschudyi probably belonged to a member of the Euphorbiaceae; he cites Tschudy (1973) as noting a resemblance to the family Picrodendraceae. Zamaloa and Romero (1990) and Martin (1974), referring to the southern hemisphere species of Malvacipollis, emphasize the difficulties of distinguishing between pollen of the families Malvaceae and Euphorbiaceae. Zamaloa and Romero felt comfortable, however, with, an assignment of their M. argentina grains to the Malvaceae.

**Paleoenvironmental Notes.** Frederiksen (1980a) found this taxon infrequently in his Claiborne and Jackson samples.

Modern Malvaceaean species in the Big Thicket of Texas range from herbs to shrubs. Hibiscus militaris is common in open area of levees. Kosteletzkya virginica (salt marsh mallow) is typical of coastal prairies and can be found in areas of seawater incursion and natural salt outcroppings. Callirhoe papaver (winecup) is a common wildflower in uplands. (Ajilvsgi, 1979) Malvaceous plants in British Guiana grow in swamps and marsh forests, along rivers, in strand scrub, and in mangrove along rivers. (Van der Hammen, 1963)

**Occurrence.** Less than 1% in five samples from San Miguel and absent from Lake Somerville.

**Range.** Frederiksen (1988) gave the range of Malvacipollis cf M. tschudyi as Lower to Middle Claibornian.

## Genus Anacolosidites Cookson & Pike 1954

**Description.** Grains small, subtriangular in polar view with straight to slightly concave sides; equatorial diameter 19-24 μm. Pores usually close to the angles Exine 1.5 to 2.5 μm; sexine as thick as nexine; sculpture ill-defined, ?finely reticulate.

**Affinity.** Anacolosa in the Oleaceae according to Frederiksen (1981).

**Occurrence.** 1% from one sample from Sequence E at San Miguel. Absent at Lake Somerville.

**Range.** Frederiksen (1980a) found only one specimen from the Jackson of Alabama; Engelhardt (1964) reported examples of a species from the Claiborne. Cookson and Pike (1954) gave the genus range as Eocene.

Genus Monosulcites Couper 1953 emend. Potonié 1958

Monosulcites asymmetricus Frederiksen 1973

Monosulcites asymmetricus Frederiksen 1973, p. 79, pl. 2, figs. 23, 28-29, 34-35.

**Affinity.** According to Frederiksen (1981), probably Palmae.

**Paleoenvironmental Notes.** Berry (1924) described numerous occurrences of palm pollen in the Texas Eocene, mostly in the Jackson age Fayette sandstone. These included Phoenicites?, a fragment of a pinnate palm leaf which could have belonged to a number of palm genera, from Fayette Sandstone localities near Millican and Wellborn, Brazos Co., TX; Palmoxylon lacunosum from numerous Texas locations; palm nut or Palmocarpon from the Yegua Fm. of Brazos County; and Palmocarpon sessile, a chunk of inflorescence from near Millican, Brazos County.

On their pollen diagram from Recent Borneoan peats, Anderson and Muller (1975) charted several palm genera derived from sporophytes commonly growing in peat swamps. These included Calamus, which grows along the margins of swamps; Cytostachus, which is abundant on shallow peat along the transition zone from mangrove and on the perimeter of swamps, and a species of Oncosperma which is common along inland margins of the mangrove belt and in riparian fringes.

Van der Hammen (1963) described a palm marsh forest in coastal deltas of British Guiana. Palms were found growing in swamp forest, rain forest, and on sand ridges. He pointed out that the genus Mauritia occurs in the low parts of savannas, in swamps, and on low river banks.

In his study of the Orinoco Delta, Muller (1959) described an open, bush-like palm swamp, "...with emerging clusters of palms, mainly Mauritia sp., Manicaria sacchifera, and Euterpe sp." This type of swamp is located in the central delta area, where the soil is permanently waterlogged, few fluctuations occur in water level, and pure peat is formed. Some palms also grow in the upper deltaic swamp forest, where there are more marked seasonal variations in water level. Mauritia also occurs as scattered, stunted individuals in the central deltaic, permanently inundated, "herbaceous swamp." This also is a peat forming environment. Muller suggested that the distribution of these vegetation types in the central deltaic back swamp represents a succession controlled by decreasing nutrient availability. The latter two vegetation types also grow on peat in the outer delta, where tidal influences are most important. According to Muller, the pollen percentages of Mauritia, which is a spiny, medium

heavy grain, fluctuate strongly in relation to proximity of Mauritia populations, and reach 30% in the source area. He noticed a similar pattern with psilate palm types.

**Occurrence.** Less than 1% in five samples from San Miguel and absent at Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg on the Gulf Coast (Frederiksen, 1980a).

Genus Monocolpopollenites Pflug & Thomson in Thomson & Pflug 1953 emend. Nichols et al. 1973

Monocolpopollenites tranquillus (Potonié) Thomson and Pflug 1953

Pollenites tranquillus Potonié, 1934, p. 51, pl. 2, figs. 3, 8.
Monocolpopollenites tranquillus (Potonié) Thomson and Pflug, 1953, p. 62-63, pl. 4, figs. 24-37, 39-47.
Palmaepollenites tranquillus (Potonié) Potonié, 1958, p. 97, pl. 11, fig. 138.
Monosulcites sp., Tschudy and Van Loenen, 1970, pl. 1, fig. 15.

**Description.** 20-45 μm. Exine to 2 μm thick, always scabrate or intrapunctate. The equator has a characteristic asymmetry four to six true, loop formed contour, with rounded-off corners. Two corners are situated on the intersection with the colpus-plane, one close (or shut) by that an acute one as the other. The colpus lies not exactly symmetrically. Colpus bulge about 1 μm wide, itself towards the end scarcely tapered. Colpus seldom gaping. Figure tabular. (Translated from Thomson and Pflug)

**Affinity.** Palmae, according to Frederiksen (1980a).

**Occurrence.** To 4% in 24 samples from San Miguel and up to 4% in seven lignites at Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg of the Gulf Coast (Frederiksen, 1980a).

## Genus Sabal Adanson

### Sabal cf. S. granopollenites Rouse 1962

Sabal granopollenites Rouse, 1962, p. 202, pl. 1, figs. 3-4.

Sabal cf. S. granopollenites Rouse. Frederiksen 1980a, p. 45, pl. 9, figs. 6-8.

**Description.** Pollen monocolpate, fusiform in outline, coarsely granulate to weakly reticulate. The single colpa is long and narrow with weak margins. Size range 28-32 μm.

**Affinity.** Engelhardt (1964) noted a strong resemblance of his Sabalpollenites to modern Sabal sp. (Palmae), or palmetto.

**Paleoenvironmental Notes.** Frederiksen (1985) considered Sabal to be a widespread member of the shrub layer during the Eocene. Daghlian (1978) reported Sabal dortchii Daghlian megafossils, identified by cuticle to the genus Sabal, from the Middle Eocene of Tennessee. Palm leaf fossils were closely associated with backswamp or flood plain deposits and abandoned channel sediments. A. Raymond (oral commun., 1993) suggested that Sabal-type palm macrofossils may be contained in channel sediments from Welch Park at Lake Somerville. Potter (1976), in his investigation of a oxbow lake in the Middle Eocene of Tennessee, interpreted the increase of

Sabalpollenites as an invasion of palms into a lowland community.

Dilcher (1973) remarked, "There are several modern species of Sabal, nearly all of which have been grown in Florida and observed to recover very well from rather severe winter frosts. Thus the use of palms as an indication of a tropical or subtropical climate is open to question." (p. 43)

Berry (1924) identified macrofossils found in the Fayette Sandstone (Jackson Group) of Webb County, Texas as Sabalites vicksburgensis. He noted that it resembled in habitat the modern Sabal palmetto by which he meant it preferred environments near the coast.

Fan palms, like Sabal palmetto, are more common in subtropical zones of Central America, but can occur in tropical zones (Holeridge et al., 1971). The most common habitat is sandy or swampy coastal regions (Corner, 1966). They are most abundant where the mean annual temperature exceeds 24 degrees C, but a few grow in cooler forests. Frederiksen (1980c) reports that Sabal grows in summer-dry and/or arid subtropical, humid subtropical, winter-dry tropical, and wet tropical climates. Ajilvsgi (1979) described palmetto oak flats in the Big Thicket of Texas, which occupy the lowest, flattest terrain of the Big Thicket including broad swamplands and tortuous bayous. Dwarf palmetto is the most distinctive plant in this association, and may cover the forest floor with little or no vegetation between. In this environment, water stands for fairly long periods of time, and in the summer, evaporation causes large areas of cracked clayey soils be exposed.

Sabal secretes nectar freely, and is visited by bees (Lovell, 1926).

**Occurrence.** To 8% in 32 samples from San Miguel and 1% in one lignite sample from Lake Somerville.

**Range.** Claiborne to Lower Jackson of the Gulf Coast (Frederiksen, 1980a).

Genus Arecipites Wodehouse 1933 emend. Nichols et al. 1976

Arecipites columellus Leffingwell 1971

Sabalpollenites cf. S. convexus Thiergart, 1938. Engelhardt, 1964, p. 71. pl. 2, fig. 14.
Monosulcites sp., Tschudy and Van Loenen, 1970, pl. 1, figs. 10, 14.
Arecipites columellus Leffingwell, 1971, p. 40-41, pl. 7, figs. 1-2.

**Description.** Monosulcate, sulcus extending the entire length of the grain, never expanding at the ends; shape elongate ellipsoidal; exine 1.2 to 1.5 μm thick, and thinnest adjacent to the sulcus; exine partially tectate, forming distinct ectosexinous and columella layers that are best seen in optical section, sexine thicker than nexine; reticulate, lumina about 0.5 μm wide and of uniform size; grain size (15 specimens) 30 to 40u X 20 to 25 μm.

**Affinity.** According to Frederiksen (1980a), "this species is identical with modern pollen of Serenoa serrulata (Michx.)(Palmae)(p. 45)". Arecipites grains in the San Miguel and Lake Somerville deposits are fairly similar to S. serrulata pollen pictured by Kedves (1980, p. 363).

**Paleoenvironmental Notes.** Elsik (1978) interpreted a preponderance of Calamuspollenites-Arecipites pollen as indicating an herbaceous community inhabiting Calvert

Bluff (Paleocene) and Yegua-Jackson marshes in the absence of the still-evolving forbs. Potter (1976) hypothesized that the increase of Arecipites in the upper part of a lignite seam represented an invasion of palm trees during the final stage of a Middle Eocene oxbow lake. Farley (1990) noted a low of Arecipites in the levee-crevasse splay environment of the Early Eocene of Wyoming.

Serenoa, or saw palmetto, is a branching palm closely resembling and with habitats similar to that of Sabal (Corner, 1966). Frederiksen (1980c) reported Serenoa as growing in humid subtropical and winter-dry tropical regions.

Lovell (1926) mentions Serenoa repens as a honey producer.

**Occurrence.** Appears in 114 levels in values to 39% at San Miguel; to 14% in 15 lignites and the clastic sample at Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg of the Gulf Coast (Frederiksen, 1981).

## Genus Calamuspollenites Elsik in Stover et al. 1966

### Calamuspollenites eocenicus Elsik and Dilcher 1974

Calamuspollenites eocenicus Elsik and Dilcher, 1974, p. 74, pl. 28, figs. 66-67.

**Description.** Bilateral pollen grains with one furrow which reaches the apices; furrow is closed to open. Furrow margin when split is thin and recurved. Exine of three layers; outer layer punctate with scabrate-microrulgulate ornamentation. Dimensions about 20 X 30 μm. Furrow width depends on whether or not the exine is split and recurved and degree of compression

and folding of grain. Exine slightly thicker than 1 μm (but less in floor of furrow). Foot layer or endexine and columellate layer about equal thickness; less than 0.5 μm each. Tectum very thin, punctae very small, microrugulate 0.5 μm or less wide and generally very short.

**Affinity.** Probably Palmae (Frederiksen, 1980a)

**Occurrence.** Less than 1% in one sample from Sequence C of the San Miguel Lignite. Less than 1% in two lignites from Lake Somerville.

**Range.** Claiborne to Jackson (Frederiksen, 1980a)

## Genus Liliacidites Couper 1953

**Affinity.** According to Frederiksen (1983), the genus Liliacidites represents "Probably mainly Palmae" (p. 46), but he added the possible choices Liliaceae, Amaryllidaceae, and Iridaceae. Frederiksen believed that it was impossible to determine on the basis of pollen alone which genera of Palmae produced individual species of Middle Eocene Liliacidites. Engelhardt (1964) noted that Couper (1953) erected this genus for specimens which could not be placed more accurately in other genera, and that pollen with similar morphology occurs in the Palmae.

**Paleoenvironmental Notes.** Elsik (1978) used sparse Liliacidites occurrence in the Calvert Bluff (Paleocene) and common Liliacidites occurrence in the Yegua-Jackson to indicate a marsh environment. The "marsh assemblage" was only a short episode in the beginning of peat development. Two species of Liliacidites were found by Potter (1976) to be conspicuously present at the top of a Middle Eocene lignite. This was interpreted as an invasion of palms surrounding a lowland community

surrounding a freshwater pond, a late stage of the infilling of an oxbow lake. Farley (1990) found the highest amounts of Liliacidites in swamp-facies carbonaceous shales in his study of the Early Eocene of Wyoming.

**Range.** From near the top of the Tallahatta Fm. (Middle Eocene) into the Oligocene (Frederiksen, 1988).

Liliacidites tritus Frederiksen 1980

Liliacidites variegatus Couper, 1953 [misidentified]. Engelhardt, 1964, p. 71, pl. 2, figs. 13-16.
Liliacidites sp., Tschudy and Van Loenen 1970, pl. 1, fig. 16.
Liliacidites tritus Frederiksen, 1973, p. 80-81, pl.3, figs. 13-16.
Liliacidites tritus Frederiksen, 1980a, p. 46, pl. 9, figs. 14-15.

**Description.** Size 32-39 μm, mean 34 μm, holotype 33 μm. Outline more or less oval; may be slightly polygonal or asymmetrical;ends rounded or slightly pointed; length /width 1.3-1.9. Exine about 0.3 μm thick excluding ornamentation; distinctly reticulate, the muri clavate in optical section and simpli- to duplibaculate in design. Muri 1 μm high and 0.7-1 μm wide; lumina round to polygonal to oval, 0.5 x 0.5 2-0.5 x 1 μm in size on proximal side; lumina may be slightly smaller on distal side near sulcus. Sulcus extends full length or nearly full length of grain; sulcus gaping, slightly open all along its length or edges overlapping; edges of sulcus turned up so that the edges look thickened.

**Affinity.** L. tritus is "Very similar to modern pollen of Pseudophoenix sp.," according to Frederiksen (1980a, p. 46.)

**Occurrence.** To 2% in 18 samples from San Miguel. To 7% in two lignites at Lake Somerville.

Liliacidites vittatus Frederiksen 1980

Liliacidites sp., Tschudy and Van Loenen, 1970, pl. 1, figs. 14-15.

Liliacidites vittatus Frederiksen, 1973, p. 80, pl. 3, figs. 1-5.

Liliacidites yeguaensis Elsik, 1974b, p. 98, pl. 1, figs. 14-15.

Liliacidites vittatus Frederiksen. Frederiksen, 1980a, p. 46, pl. 9, figs. 16-17.

**Description.** Size 28-38 μm, mean 34 μm, holotype 35 μm. Broadly lenticular in outline, the ends slightly pointed; length/width 1.1-1.5. Reticulate; muri in optical section ribbon-like, discontinuous and clavate, with the clavae 0.5-3 μm apart; between clavae, muri are supported by thin bacula. Exine including reticulum 2 μm thick; exine proper 0.5-.07 μm thick;exine proper 0.5-0.7 μm thick, baculate interval 0.3-0.5 μm high, muri 0.7-1 μm high. Muri 1 μm wide and duplibaculate in design; lumina polygonal, about 2-3 μm in diameter on proximal face, 10-12 lumina present down length of grain; lumina may be smaller near sulcus. Sulcus extends full length or nearly full length of grain; usually slightly open, without thickened margins.

**Affinity.** Not known.

**Occurrence.** To 19% in 97 samples from San Miguel. To 15% in 15 lignites and the clastic sample at Lake Somerville.

## Genus Spinozonocolpites Muller 1968

### Spinozonocolpites echinatus Muller 1968

**Description.** Oval, flattened along the polar axis, generally separated by a continuous equatorial aperture in two more or less equal parts; borders of apertures somewhat irregular and with a torn appearance, with reduced ectexine thickness; wall ± 1 μm thickness, surface bearing scattered spines; endexine thin, <1 μm thick; columellae fused into a finely reticulate pattern; muri < 1 μm; lumina rounded, even in size, < 1 μm across; spines 5-7 μm long, uniformly spaced, conical, with a fairly blunt, rounded apex and an often slightly expanded base, flat underneath, apparently resting on separated columellae. 33 (35) 43 μm (8 specimens).

**Affinity.** According to Muller (1968), these grains have "...identity with the pollen of the palm genus Nypa without reasonable doubt." (p. 12)

**Paleoenvironmental Notes.** Because S. echinatus is almost certainly the pollen of Nypa, a mangrove palm, it has been used as an indicator of a marine-influenced, saline environment. Srivastava and Binda (1991), in a study of the early Tertiary of Saudi Arabia, stressed the association of S. echinata with open-marine dinoflagellates. They believed their S. echinata mangrove to be part of a continuum of tropical estuarine vegetation. It was included in the most marine "sea-proximal zone," an "...area under the influence of the highest and lowest tides..." and "...supporting mangrove vegetation." (p 57). Nypa was the "most distinctive" palynomorph in a lignite from the Claiborne Group of Webb Co., TX (Westgate and Gee, in press). The presence

of Nypa suggested to these authors tropical to subtropical conditions, as well as an intertidal area with water temperatures greater than 24 degrees C. S. echinatus was also an important constituent of an early to Middle Eocene (?) intertidal sequence from Morocco (Fechner, 1988). Again, the presence of S. echinatus indicated a mangrove swamp environment.

Anderson and Muller (1975) found Nypa pollen only in clays in the basal portion of their profile from a modern swamp in Sarawak. Flenley (1979) notes that Nypa grows in brackish water, usually at the landward side of mangrove swamps.

Flenley (1979) also gave the present distribution of Nypa as mainly Ceylon, Assam, Burma, Malesia, and China.

**Occurrence.** Absent at San Miguel and 1% in the clastic sample at Lake Somerville.

**Range.** Nypa has been recorded from the Paleocene/Eocene of West Africa, France, Britain, Poland, Southern U.S.S.R. [sic], Egypt, Central India, Borneo (pollen), Brazil, and Texas, according to Flenley (1979). Citing Muller (1970), he charted the first appearance of Nypa pollen in the Senonian.

## Genus Cupuliferoidaepollenites Potonié 1960

### Cupuliferoidaepollenites liblarensis (Thomson) Potonié

Pollenites liblarensis Thomson in Potonié et al., 1950, p. 55, pl. B, figs. 26-27.
Tricolpopollenites liblarensis (Thomson) Thomson and Pflug, 1953, p. 96, pl. 11, figs. 111-132.
Cupuliferoidaepollenites liblarensis (Thomson) Potonié, 1960, p. 92, pl. 6, fig. 94.

Tricolpopollenites liblarensis (Thomson) Thomson and Pflug, 1953. Tschudy, 1973, p. B18, pl. 4, figs. 31-33.

**Description.** 20-30 μm. Outline spindleshaped or ellipsoidal. Width-length index between 0.5 and 0.8. Exine nearly smooth to vaguely interrugulate.

**Affinity.** Frederiksen (1980a) suspected that Cupuliferoipollenites pollen was Fagaceous, also Leguminosae in part. Crepet and Daghlian (1980) removed a very similar pollen type from a Castaneoid (Fagaceae) inflorescence from the Claiborne Group of Tennessee. These grains were prolate with an average polar diameter of 15.0 μm and an average equatorial diameter of 9.0 μm (P/E=1.67). SEM photography showed a surface consisting of striate, anastomosing fused ridges characteristic of modern Castaneoids. Leaves of the extinct Fagaceous genus Dryophyllum and castaneoid fruits were found in the same sediments.

**Paleoenvironmental Notes.** Cupuliferoidaepollenites grains dominated Potter's (1976) clay zone from the Claiborne of Tennessee, with percentages of over 60% in this zone. He believed that this type represented "...waterborne and windborne background and local pollen derivation" (p. 83) One upper Eocene lignite seam from Hungary was co-dominated was co-dominated by Cupuliferoidaepollenites liblarensis and Cupuliferoipollenites cingulum. (Kedves, 1965). Pflug (1952) found large proportions of C. liblarensis associated with the brown coal seams in Germany. Frederiksen (1985) described Pflug's Interpretation: "Rapid subsidence caused flooding of the swamp. The water was too deep for trees to grow. The main sporomorph type in the marsh or shallow lake deposits was the Cupuliferoidaepollenites liblarensis type,

produced by Fagaceous trees in the closed forest outside the swamp." (p. 58)

Anderson and Muller (1975) figured up to 30% Lithocarpus/Castanopsis in a profile from a modern Sarawak peat swamp. The high percentages were found in a zone dominated by Shorea albida, which represents roughly a midpoint in the plant succession. Pollen of the Fagaceous taxa are found in percentages to about 10% in surface samples representing the lower half of the successional sequence.

Many modern species of the Castaneoidea are thought to be insect pollinated (Crepet and Daghlian, 1980); Lithocarpus is primarily entomophilous (Lewis et al, 1980; Flenley, 1979). According to Flenley, both Lithocarpus and Castanopsis are common in Malesian lower montane forests. Castanopsis is wind-pollinated and exports large amounts of pollen.

**Occurrence.** To 81% in 134 levels at San Miguel and to 18% in 13 lignites and the clastic sample at Lake Somerville.

**Range.** Frederiksen (1981) found this species in samples from the Upper Claiborne to the Lower Vicksburg.

## Genus Foveotricolpites Pierce 1961

### Foveotricolpites prolatus Frederiksen 1973

Foveotricolpites prolatus Frederiksen, 1973, p. 81, 84, pl. 3, figs. 17-22

**Affinity.** According to Frederiksen (1981), similar to pollen of modern Spartium junceum L. (Leguminoseae).

**Occurrence.** 1% in four samples from San Miguel. Absent at Lake Somerville.

**Range.** Claiborne to Lower Vicksburg (Frederiksen, 1981)

## Genus Quercoidites Potonié 1960

**Paleoenvironmental Notes.** The Quercoideae were well-developed by the beginning of the Oligocene, when, because of a climatic deterioration and a sudden drop in sea level, they began to dominate the flora. At one Catahoula Fm. (Oligocene) locality, the oak pollen comprised 85% of the palynoflora (Daghlian and Crepet, 1983). The authors believed that this evolutionary success was due to hybridizations caused by Eocene climatic change.

Modern-day temperate oaks are wind pollinated, but tropical oaks are primarily insect pollinated (Lewis et al., 1983). The various temperate oak species may live anywhere from dry, sandy soils to swamps, as with Quercus bicolor. According to Flenley (1979), Quercus grains have "high relative export."

Quercoidites sp. was characteristic of the clay zone in Potter's 1976 study of the Tennessee Claiborne.

### Quercoidites inamoenus (Takahashi) Frederiksen 1980

Tricolpopollenites inamoenus Takahashi, 1961, p. 313, pl. 22, figs. 42-49.

Quercoidites cf. Q. henrici (R. Potonié, 1931) Potonié, Thomson, and Thiergart. Engelhardt 1964, p. 71, pl. 2, fig. 15.

Quercus sp., Fairchild and Elsik, 1969, p. 84, pl. 37, fig. 22.

Tricolpopollenites sp., Tschudy and Van Loenen, 1970, pl. 4, fig. 2.

Quercus sp., Elsik, 1974b, pl. 4, fig. 2.
Quercoidites inamoenus (Takahashi) Frederiksen, 1980a, p. 47, pl. 10, figs. 3-8.

**Affinity.** Frederiksen (1980a) assigned this highly variable species to Quercus or to the extinct Fagaceous genus Dryophyllum. He included a large range of colpus-pore forms within this species, including both tricolpate forms with simple colpi or with geniculi, and tricolporate forms, with ora present as slits. These tricolporate forms have been isolated by Daghlian and Crepet (1983) from oak catkins from the Oligocene Catahoula Formation near Huntsville, Texas. C. Ferguson (oral commun., 1988) removed similar pollen from shales at the same site. This tricolporate "oak" pollen is not readily recognizable as oak either to myself nor to other palynologists experienced with Quaternary oak pollen (J. Jones, 1988, oral commun.; S. Hall, 1988, oral commun.), nor does it resemble modern oak pollen pictured by Lieux (1980).

**Occurrence.** To 10% in 96 levels at San Miguel and to 3% in four lignites and the clastic sample at Lake Somerville.

**Range.** From just above the base of the Lisbon Fm. (Middle Claiborne) into the Oligocene (Frederiksen, 1988).

Quercoidites microhenricii (Potonié) Potonié 1960

Pollenites microhenricii Potonié, 1931, p. 26, pl. 1, fig. V19c.
Pollenites henrici microhenrici (Potonié) Potonié and Venitz, 1934, p. 27.
Tricolporopollenites microhenrici (Potonié) Thomson and Pflug, 1953, p. 96, pl. 11, figs. 62-110.

Quercoidites microhenrici (Potonié) Potonié, 1960, p. 93.

**Description.** 20-30 μm. Outline spindleshaped. Width-length index ca. 0.5, but also somewhat more or less. Very complex, here and there likely a larger quantity of botanical units are embraced. lets separate from one another scarcely. Viewed beside size and shape is the intergranulate or intrabaculate structure. Ektexine and endexine equally strong. Several have geniculi.

**Affinity.** Frederiksen (1980a) speculated that Q. microhenricii was derived from a Fagaceous sporophyte.

**Occurrence.** To 57% in 101 levels from San Miguel and to 2% in two lignites and the clastic layer at Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1981). Elsik (1968a) reported this taxon from the Paleocene Rockdale lignite.

## Genus Fraxinoipollenites Potonié 1960

BT-68, ??Rubiaceae?? Traverse, 1955, p. 75, fig. 13 (138).

Tricolpites sp. 3 Engelhardt, 1964, p. 72, pl. 2, fig. 19.

Tricolpopollenites sp., Tschudy and Van Lonen, 1970, pl. 4, figs. 9, 14.

Fraxinoipollenites spp., Frederiksen, 1980a, pl. 10, figs. 14-17.

Fraxinoipollenites medius Frederiksen, 1980a, pl. 10, figs. 11-12.

**Description.** Tricolporate pollen grain with long furrows quite unmodified except for slight margos.

Reticulate sculpture with wide muri and large lumina. Reticulum has columellate structure.

**Affinity.** Probably not Fraxinus, according to Frederiksen (1980a).

**Paleoenvironmental Notes.** Fraxinus megafossils are common in Claiborne Group sediments, but dispersed pollen grains in the same beds assigned to Fraxinus by Taylor (1987) are not of this type (Call and Dilcher, 1992).

### Small Species Group

**Paleoenvironmental Notes.** Modern Fraxinus is wind pollinated (Lewis et al., 1983)

**Occurrence.** To 12% in 85 samples from San Miguel and to 4% in 11 lignites and the clastic sample at Lake Somerville.

### Large Species Group

**Occurrence.** Up to 5% in 26 samples from San Miguel. 1% in one lignite sample and 2% in the clastic sample at Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1981)

## Genus Platanus Linneaeus

### Platanus occidentaloides Frederiksen 1980

Tricolpites sp. 2. Engelhardt, 1964, p. 72, pl. 2, fig. 18.

Tricolpopollenites sp., Tschudy and Van Loenen, 1970, pl. 4, figs. 3-6, 10, ?12.

Tricolpites n. sp. A (microreticulate) Tschudy, 1973, B13, pl. 2, figs. 11-12 only.
Platanus occidentalis Frederiksen, 1980a, pp. 48-49, pl. 10, fig. 19.

**Affinity.** According to Frederiksen (1980a), P. occidentaloides is "Very similar to Platanus occidentalis L. except that the fossils are slightly larger and the colpi are slightly deeper than in the modern grains." (p 49). My few specimens, as well as the one illustrated by Frederiksen (1980a) vary markedly from the modern specimen pictured by McAndrews et al. (1978), especially in relation to the depth of the colpus.

**Description.** Polar axis 26-35 μm, equatorial axis (in polar view) 22-35 μm, holotype 31 μm. Tricopate. Spheroidal to subprolate; broadly rounded at the poles. Exine 1.25-1.5 μm thick including reticulum; "nexine":"endosexine":"ectosexine" ratio about 1:15:1. Lumina a little less than 0.5 μm in diameter. Colpi extend 2/3-3/4 length of grain and are moderately deeply incised; colpi appear narrow in equatorial view but gape widely in polar view; edges of colpi very rough and sometimes beaded; margins thickened little if any.

**Paleoenvironmental Notes.** Macrofossils of Platanus were found in the Eocene Clarno Nut Beds of Oregon. The wood and fruit morphology were similar to those of modern specimens, but the leaves were primitive (Manchester, 1981). P. neptuni, found in the Eocene and Oligocene of Central Europe, co-occurred with Dryphyllum and Laurophyllum and was often accompanied by evergreen arborescents and drought resistant species (Hably, 1980).

In Frederiksen's (1981) Eocene samples from the southeastern United States, Platanus pollen was more

common in clastics and was thought more likely to have come from trees outside the peat-forming environment.

Platanus (sycamore) trees grow in most of eastern north America, in moist or wet alluvial sites (Gleason and Cronquist, 1963). It is "...one of the commonest of streambank and bottomland trees...(p. 197)", according to Harlow (1957). P. occidentalis is a pioneer plant growing below levees and on low banks in the Big Thicket of Texas (Ajilvsgi, 1979). Frederiksen (1980b) reported that Platanus grows in summer-dry subtropical and or semi arid, humid subtropical, and winter-dry tropical regions. Members of the Platanaceae are wind pollinated and release large amounts of pollen (Lewis et al., 1983).

**Occurrence.** Less than 1% in 20 samples from San Miguel and 1% in one sample from Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a). Not found below the uppermost Claiborne by Tschudy (1973).

## Genus Salixipollenites Srivastava 1966

### Salixipollenites parvus Frederiksen, 1980

Salixipollenites parvus Frederiksen, 1980a, p. 49, pl. 10, figs. 20-27.

**Description.** Size 15-24 μm, mean 20 μm, holotype 16 μm. Tricolpate. Subprolate to prolate; broadly rounded at the poles. Exine about 1 μm thick including ornamentation. Reticulum medium coarse in relation to small size of the grain--lumina are 0.5-1 μm in diameter. Muri slightly less than 1 μm high and about 0.5 μm wide, clavate in optical section and distinctly simplibaculate in design. Colpi extend 2/3 to 3/4

length of grain, inner edges of colpi appearing thickened.

**Occurrence.** To 4% in 47 levels at San Miguel and to 6% in 13 lignites from Lake Somerville.

**Range.** Near the top of the Lisbon Fm. into the Oligocene (1988).

## Genus Fraxinus Linnaeus

### Fraxinus? pielii Frederiksen 1980

Fraxinus? pielii Frederiksen, 1980a, p. 49, pl. 10, figs. 28-32.

**Description.** Size 24-33 μm, mean 28 μm, holotype 23 X 26 μm. Oblate; outline square, with sides slightly to moderately convex. Tetracolpate, colpi 1.5-3 μm deep, margins lacking. Exine 1 μm thick; tegillate; ectosexine:endosexine:nexine ratio about 1:1:1, finely infrareticulate to finely infragranulate, the lumina or grana 0.3-0.5 μm in diameter.

**Affinity.** Frederiksen (1980a) observed that this species has a finer reticulum than modern Fraxinus.

**Occurrence.** To 1% in four samples from San Miguel. Absent at Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a).

## Genus Rousea Srivastava 1969

### Rousea araneosa (Frederiksen) Frederiksen 1980

Albertipollenites? aranosea Frederiksen 1973, p. 84, pl. 3, figs. 30-34.

Rousea araneaosa (Frederiksen) Frederiksen 1980, p. 49, pl. 10, figs. 33-34.

**Description.** Size 21-37 μm, mean 29 μm, holotype 33 μm. Prolate, outline oval, poles broadly to narrowly rounded. Tricolpate, colpi extending nearly full length of grain, ends of colpi typically broadly rounded, colpi margins slightly thickened. Bases of colpi sometimes torn or ragged-some specimens appear to be raggedly tricolporate. Exine excluding ornamentation 1 μm thick; sexine-nexine 3:1. Reticulate, the muri clavate in optical section, clavae 0.7-1 μm high, muri 0.3 μm wide, lumina 1.5-2.5 μm in diameter.

**Affinity.** Frederiksen gave the affinity of R. araneosa as "...probably Bignoniaceae. (p. 49)".

**Paleoenvironmental Notes.** One member of the Bignoniaceae, Catalpa bignonioides, lives on riverbanks and swamp margins in the southeastern United States. Enallagma latifolia (black-calabash) inhabits rich, moist soil near salt water in Florida and the Caribbean. The family also includes several vines. (Harrar and Harrar, 1962)

**Occurrence.** Less than 1% in 11 samples from San Miguel and 1% in one lignite from Lake Somerville.

**Range.** Middle of the Lisbon Fm. (Middle Eocene) into the Oligocene (Frederiksen, 1988).

## Rousea monilifera Frederiksen 1981

Tricolpopollenites sp., Tschudy and Van Lonen 1970, pl. 4, figs. 20 a-b.

Rousea monilifera Frederiksen 1981, pl. 10, figs. 20 a-b.

**Description.** Size 36-45 μm, mean 40 μm, holotype 41 μm. Tricolpate. Subprolate to prolate, rarely

spheroidal; broadly rounded at poles. Exine 0.5-1 μm thick excluding ornamentation. Coarsely reticulate; muri 2-3 μm high, clavate in optical section, heads of clavae rounded or more often radially elongate; muri 0.5-0.8 μm wide and coarsely beaded in design (simplibaculate), the beads 0.7-1 μm in diameter, that is, of greater diameter than the width of the muri. Muri may be somewhat discontinuous. Lumina about 2-3 μm in diameter, except those near the colpi, which are only about 1 μm; lumina polygonal to rectangular. Colpi deeply invaginated, extending nearly full length of grain, 0.5-2 μm wide, with edges not thickened.

**Affinity.** According to Frederiksen (1981), very similar to Armeria (Plumbaginaceae); also similar to Amanoa (Euphorbiaceae), according to Elsik and Dilcher (1974).

**Occurrence.** 1% in four samples from San Miguel; absent from Lake Somerville.

Genus Striatopollis Krutzsch 1959

Striatopollenites terasmaei (Rouse) Frederiksen 1980

Striatopollenites terasmaei Rouse, 1962, p. 212, pl. 4, figs. 30, 35.

Striatopollis terasmei (Rouse) Frederiksen, 1980a, p. 50, pl. 11, fig. 6.

**Description.** Pollen grains elliptical in outline. Tricolpate, with the colpas narrow and simple. Exine striate, with some 20-30 longitudinal ridges covering the surface. The ridges are about 2μm apart and curve inward at the poles, as in species of Schizaea and Ephedra. Size range 24 to 26 μm.

**Occurrence.** Less than 1% in four levels from San Miguel. Absent from Lake Somerville.

**Range.** Bashi-Hatchetigbee Fm. (Late Sabininan, Lower Eocene) into the Oligocene (Frederiksen, 1988)

## Genus Cupuliferoipollenites Potonié 1960

### Cupuliferoipollenites spp.

Cupuliferoipollenites cf. C. insleyanus (Traverse, 1955) R. Potonié, 1960. Engelhardt, 1964, p. 72-73, pl. 2, fig. 23.

Castanea sp., Fairchild and Elsik, 1969, p. 83, pl. 37, fig. 6.

**Description.** 10-30 μm, most not over 28 μm, Outline spindle-shaped to cylindrical, also egg-shaped. Not spherical or biconical. Cavernae ± parallel up to the poles extending. Exine smooth or weakly interrugulate.

**Affinity.** Frederiksen (1981), citing his own unpublished data, stated that Cupuliferoipollenites came from "Mainly Dryophyllum; (an extinct genus of Fagaceae)...perhaps few of these grains were produced by Castanea or and (or) Castanopsis." (p. 50) Recently, Jones (1988) pointed out that the type specimen of Dryophyllum should be assigned to the Juglandaceae, however, he added that most of the species included in the genus Dryophyllum now need to be reassigned to an undesignated Fagaceous genus. Nichols (1970), who examined modern grains of Castanea, felt that his C. cingulum grains (probably equivalent to Frederiksen's Cupuliferoipollenites spp.) were without a doubt referable to that modern genus. Engelhardt (1964) also mentioned the resemblance of this taxon to Castanea.

For a further discussion of Cupuliferoipollenites, see the section on "Scenario 3: Mangroves" in the chapter on "Paleoecology."

**Taxonomic Notes.** Frederiksen (1984, written communication) refers to the taxa Cupuliferoipollenites, Siltaria, and Araliaceoipollenites as "...problematic." They form a sculptural continuum, and have very similar morphology. Cupuliferoipollenites grains are, by his definition, psilate.

**Paleoenvironmental Notes.** Pflug (1952) believed that "Castanea" pollen from German brown coals came from low trees or shrubs because of its limited dispersal in the sediments. Cupuliferoipollenites made up generally 69 or more percent of lignite assemblages in Potter's study of the Claiborne of Tennessee. It was also present at levels up to 45% in the clay layer. He thought that Cupuliferoipollenites was locally derived. Dilcher (1973) discussed the taxon in Tennessee clay samples, offering the opinion that "The abundance of Castanea pollen in all of the clay samples studied suggests that this pollen came from wind-pollinated trees. According to Faegri and Van der Pijl (1966), tropical species of Castanea are insect-pollinated and would not be expected to yield abundant pollen. Thus the abundance of Castanea pollen in these sediments is an indirect indication that a somewhat temperate climate was present in the Mississippi embayment area during the Middle Eocene." (p. 55-56)

Farley (1990), in a study of palynomorph distribution in Early Eocene rocks of Wyoming, found the highest occurrence of Cupuliferoipollenites in the pond facies. He considered Cupuliferoipollenites to have been allochthonous, but possibly of local origin.

Pflug (1952) found an abundance of Cupuliferoipollenites cingulum in a German Early Eocene lignite. His interpretation is reported by Frederiksen (1985): "Subsidence slowed, the level of the peat surface rose relative to ground-water level, and a low open forest formed a swamp vegetation that produced mostly fagaceous pollen of the Cupuliferoipollenites cingulum type plus some triporate, palm, and other pollen" (p. 58).

In the Late Oligocene Brandon lignites of Vermont, Castanea was found only in the lignites and not in the silt and clay layers (Traverse, 1955). Percentages were low, only to 4.6%.

Berry (1924) described leaf macrofossils of Dryophyllum brevipetiolatum as exceedingly common in the Fayette sandstone of East Texas. Some of his specimens were collected in Trinity and Grimes Counties, Texas.

Frederiksen (1980c) reports modern Castanea/Castanopsis from summer dry subtropical and/or semiarid, humid subtropical, winter-dry tropical, and wet tropical regions.

**Occurrence.** Present in all samples from San Miguel, with percentages to 75% and to 63% in all samples from Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a).

## Genus Chrysophyllum Linnaeus

### Chrysophyllum brevisulcatum (Frederiksen) Frederiksen 1980

Cupuliferoipollenites brevisulcatus Frederiksen, 1973, p. 85, pl. 3, figs. 28-29.
Chrysophyllum brevisulcatum Fredericksen, 1980a, p. 51, pl. 11, fig. 12.

**Description.** Size 14-21 μm, mean 17 μm, holotype 19 μm. Prolate; sides straight and poles broadly rounded. Tricolporate; colpi about 0.5 μm wide, extending only 1/2-3/5 length of grain, margins not thickened; ora lalongate, typically 1.5-2 x 4-4.5 μm. Exine 0.5-0.7 @ thick at poles and about 1 μm thick at the equator; thickening produces darkened equatorial band 6-7 μm wide. Nexine everywhere very thin. Exine psilate.

**Affinity.** Frederiksen (1980a) believed this pollen type to be morphologically identical to Chrysophyllum.

**Paleoenvironmental Notes.** Sapotaceous pollen was common in parts of the German Brown coals (Frederiksen, 1985). Frederiksen (1980a) found Chrysophyllum to be "infrequent" or "occasional" in a few of his Late Paleogene samples from the Gulf Coast; up to 40% were found in some Jackson lignites. He hypothesized that the grains had poor regional dispersal and may have been low plants.

Van der Burgh (1967) found wood and pollen of the Sapotaceae to be equally well represented in the Miocene Rhenish brown coals. Berry (1924) identified leaf fossils from the Fayette Sandstone from near Wellborn, Brazos Co., TX as Chrysophyllum preoliviforme, resembling the extant C. oliviforme of South Florida.

Chrysophyllum is a member of the family Sapotaceae, which contains 50 genera of trees and shrubs, eight of which are found in the subtropical forests of the United States. Chrysophyllum, or satinwood is a tropical genus with 65 species of evergreen trees and shrubs. The

genus currently grows in southern Florida, where favored habitats are hammocks, flatwoods, and sandy plains (Harrar and Harrar, 1962). Of the three species of Chrysophyllum found in Costa Rica, all are canopy trees. Life zones include tropical moist, tropical wet, premontain rainforest, and premontane wet (Holdridge et al., 1971). Frederiksen (1980c) reported the genus in humid subtropical, winter-dry tropical, and wet tropical regions. Pennington (1990) reported 43 species in the Neotropics. Three of these species grow in periodically flooded habitats in the Amazon Basin. A few others live in wet forests, but the majority are dry land plants.

Pollination is entirely zoophilous (Frederiksen, 1981).

**Occurrence.** To 7% in 93 levels from San Miguel, excluding Sequence B and to 21% in 12 lignites from Lake Somerville.

**Range.** From near the base of the Lisbon Fm. (Middle Eocene) into the Oligocene (Frederiksen, 1988).

## Genus Cyrillaceaepollenites Potonié 1960

**Occurrence.** "Unclassified" Cyrillaceaepollenites occurs to 6% in 32 samples from San Miguel (including Sequence B) in quantities to 14% in nine lignites and the clastic sample from Lake Somerville.

### Cyrillaceaepollenites kedvesii Frederiksen 1980

Cyrillaceaepollenites kedvesii Frederiksen 1980a. p. 51, pl. 11, figs. 13-18.

**Description.** Length of polar axis 18 to 24 μm, mean 24 μm, holotype 25 μm. Spheroidal or nearly so. Tricolporate; colpi geniculate, narrow, extending nearly

full length of grain, with thickened margines 0.5 to 1μm wide; ora lalongate, 1 to 2 μm wide and as long as 6 μm. Exine 1 μm thick; ectosexine:endosexine: nexine ratio 1:1:5:1 but collumellae are not visible or are only faintly visible; design punctate to nearly psilate.

**Affinity.** Unknown.

**Occurrence.** To 11% in 60 samples (excluding Sequence B) from San Miguel and to 1% in two lignites at Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a).

## Cyrillaceaepollenites megaexactus (Potonié) Potonié 1960

Pollenites megaexactus Potonié 1931, p. 26, pl. 1, fig. V42b.

Pollenites cingulum bruehlensis Thomson in Potonié et al., 1950, p. 56, pl. B, figs. 31-33.

Tricolporopollenites megaexactus bruehlensis (Thomson) Thomson and Pflug, 1953, p. 101, pl. 12, figs. 50-57.

Cyrillaceaepollenites megaexactus (Potonié) Potonié, 1960, p. 102.

Cyrillaceaepollenites cf. C. megaexactus. Tschudy, 1973, p. B17, pl. 4, figs. 14-17.

Cyrillaceaepollenites megaexactus (Potonié) Potonié. Frederiksen, p. 51, pl. 11, figs. 19-22.

**Description.** 10-24 μm. Outline globular. Width-length index about 1-0.9. Smooth to hyaline smooth. Frequently creased in the polar areas. Cavernae reaching the poles. Without Cavium. [Translated from Thomson and Pfulg]

**Affinity.** Cyrillaceae, Cyrilla, and (or) Cliftonia according to Frederiksen (1980a).

**Paleoenvironmental Notes.** Frederiksen (1981) believed pollen from Cyrillaceaepollenites n. sp. to have come from plants common on the coastal plain exclusive of peat-forming areas. Fechner (1988) reported Cyrillaceae from the Middle Eocene of North Africa, believing it to be a plant indicative of salt marshes because of its ability to endure physiological drought. The salt marshes at her site hypothetically stretched behind a belt of mangroves.

Traverse (1955) reported reciprocal pollen percentages of the dominants Cyrilla, found preferentially in the lignites, and Quercus. Traverse theorized that the Cyrilla plants grew around the margin of the swamp, and the Quercus pollen was exotic and indicative of deeper water.

Cyrilla racemiflora, the only modern American species, often forms nearly impenetrable thickets along the margins of swamps and in rich river bottoms, as well as on exposed sandy ridges (Harrar and Harrar, 1969). Ajilvsgi (1979) listed black titi or swamp cyrilla (Cyrilla racemiflora) as an understory element in the drier outer edges of baygall wetlands in the Big Thicket of Texas. She described it as a tall shrub or small tree which usually forms large colonies. C. racemiflora is commonly found in the understory of Taxodium wetlands in the Okefenokee Swamp and in the pocosins of North Carolina (Brown, 1990). I have seen this species as a large shrubby pioneer migrating onto the marsh plants on a floating mat in the Mississippi delta.

The monotypic Cliftonia monophylla is a bushy shrub or small understory tree found in alluvial swamps, in sandy or peaty soils, and on river bottoms subject to short periods of inundation (Harrar and Harrar, 1969).

Both Cliftonia and Cyrilla are visited by bees and are important honey producers (Lovell, 1926; Elias, 1980)

**Occurrence.** To 7% in 48 levels (excluding Sequence B) at San Miguel; to 5% in three lignites from Lake Somerville.

**Range.** Middle Talahatta Fm. (Middle Eocene) into the Oligocene (Frederiksen, 1988).

## Cyrillaceaepollenites? ventosus (Potonié) Frederiksen 1980

Pollenites ventosus Potonié, 1931, p. 555, fig. 15.
Pollenites ventosus Potonié. Engelhardt, 1964, p. 79, pl. 5, fig. 59.
Pollenites pseudolaesius Potonié 1931. Fairchild and Elsik, p. 84, pl. 37, fig. 23.
Tricolporites sp., (cf. Pollenites ventosus Potonié 1934). Tschudy and Van Loenen, 1970, pl. 4, fig. 30.
Tricolporites sp., Tschudy and Van Loenen, 1970, pl. 4, figs. 31-32.
Cyrillaceaepollenites of the Pollenites ventosus type. Tschudy, 1973, p. B17, pl. 4, figs. 20, 21.
Pollenites laesius type. Elsik 1974, pl. 4, fig. 115.
Cyrillaceaepollenites ventosus (Potonié) Frederiksen, 1980a, p. 51-52, pl. 11, figs. 23-24.

**Description.** Size 16-22 μm, mean 19 μm. Oblate. Probably tricolporate, but the ora are obscure. Colpi extend 1/2 to 2/3 (generally about 1/2) the distance to the poles. Exine 0.5 - 0.8 μm thick, sexine: nexine ratio is 3:1, integillate to indistinctly tegillate, weakly punctate to coarsely granulate; outer and inner surface smooth or rough. Most specimens have a compression fold that forms a dark, circular to rounded ring cut be the tips of the colpi.

**Affinity.** Unknown.

**Paleoenvironmental Notes.** Frederiksen (1981) noted that Pseudolaesopollis ventosa is widely distributed in Eocene detrital samples from the Mississippi embayment, but is rare in coals. He believed "...the species must have been at least partly wind pollinated; or if entirely zoophilous, the producing plants must have been very abundant and widespread on the coastal plain...these plants may have been an important plant constituent of deltaic swamp communities only during the Jackson. Even then, they were probably members of only some of those communities. (p. 524)." Elsik (1978) found an occasional sample of Manning Fm. lignite with an abundance of P. ventosa.

**Occurrence.** Up to 4% in 56 samples from San Miguel and to 8% from 13 lignites and the clastic sample from Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a).

## Genus Siltaria Traverse 1955

### Siltaria cf. S. scabriextima Traverse 1955

Siltaria scabriextima Traverse, 1955, p. 51, fig. 10 (50).

Cupuliferoipollenites sp., Tschudy and Van Loenen, 1970, pl. 7, figs. 15-16.

Siltaria cf. scabriextima Traverse. Frederiksen, 1970, p. 52, pl. 11, fig. 25.

**Description.** Tricolporate pollen grain with longitudinal furrows extending nearly from pole to pole. Large and clearly differentiated elliptical transverse furrows ca. 4μm by 6μm. Both furrows have lightly

developed margos or thickened rims. Longitudinal furrows underlain by longitudinal costae of the exine, which are cut nearly through under the transverse furrows. Scabrate sculpture. Columellate tectum. Size: ca. 24μm by 32μm. Thickness of exine: ca. 2.5μm.

**Taxonomic note.** Siltaria, according to N. Frederiksen (written commun., 1984) forms a continuum with Cupuliferoipollenites and Araliaceoipollenites (see discussion with Cupuliferoipollenites). He typified Siltaria as "finely columellate and ... punctate in plain view (that is, having pits or bumps that are 1/2 micrometer or smaller)."

**Paleoecological Notes.** Siltaria was found only in silts, and not in the lignites of the Oligocene Brandon Lignite (Traverse, 1955).

**Occurrence.** Present in 123 levels to 36% at San Miguel and to 12% in 11 lignites and the clastic sample from Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a).

## Siltaria pacata (Pflug) Frederiksen 1980

Siltaria pacata (Pflug) Frederiksen, 1980a, p. 52, pl. 11, fig. 25.
Tricolporopollenites pacatus Pflug in Thomson and Pflug, 1953, p. 99, pl. 12, figs. 118-121.
Ailanthipites pacatus (Pflug) Potonié, 1960, p. 96.

**Description.** 25-35 μm. Outline widely ellipsoidal, to almost spherical. **Width-length index between 0.7 and 1. Exine so elegantly intrabaculate, that it in the inspection appears scabrate, even shiny. Cavernae converge polewards and fall into a** Cavium. Germinal aperture similar to Tricolpites dolium.

Cavernae are essentially thin, equatorial ring extremely long.

**Affinity.** Kedves (1969) saw a resemblance with the Simaroubaceae and Cornaceae. Frederiksen (1980a) suggested Diospyros in the Ebanaceae.

**Occurrence.** One sample from sequence C from San Miguel. Absent at Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a).

## Genus Araliaceoipollenites Potonié 1960

**Occurrence.** Undifferentiated large Araliaceoipollenites grains (that is, not including A. granulatus) were present in quantities to 3% in 12 samples from San Miguel.

**Paleoenvironmental Notes.** The Araliaceae is primarily a tropical family, but some members can be found north as far as Canada. Using leaf structure, Dilcher and Dolph (1970) identified a Araliaceaen macrofossil, which they named Dendropanax, in the Claiborne Group of Tennessee.

## Araliaceoipollenites granulatus (Potonié) Frederiksen 1980

Pollenites pseudocingulum granulatum Potonié, 1931, p. 32, pl. 1, figs. 2, 6, 19, 24, 26-27.
Araliacoipollenites granulatus (Potonié) Frederiksen, 1980a, p. 52, pl. 11, figs. 29-30.

**Taxonomic note.** A. granulatus, according to N. Frederiksen (written commun., 1984), forms a continuum with Siltaria and Cupuliferoipollenites (see discussion

with Cupuliferoipollenites). Araliaceoipollenites was described as being columellate and granulate.

**Occurrence.** To 47% in 115 levels at San Miguel and to 3% in 8 lignites and the clastic sample from Lake Somerville.

**Range.** Lower part of the Middle to Upper Eocene Lisbon Fm. through the Eocene-Oligocene boundary in Alabama and Mississippi (Frederiksen, 1988).

Araliaceoipollenites profundus Frederiksen 1980

Tricolpopollenites spp. of the T. henrici type. Tschudy, 1973, p. B16, pl. 4, figs. 10-11.
Araliaceoipollenites profundus Frederiksen, 1980a, p. 53, pl. 12, figs. 2-4.

**Description.** Size 33-58 μm, mean 45 μm, holotype 41 μm. Tricolporate. Subprolate to perprolate, mostly prolate; outline lenticular with pointed to slightly flattened ends. Exine 1.5-2.5 μm thick, tegillate; ectosexine 0.5 μm thick, endosexine 0.5 -1.5 μm thick, nexine about 0.25-0.5 μm thick. Design distinctly granulate to coarsely punctate or finely reticulate. Colpi extending nearly from pole to pole, very narrow and deeply invaginated almost to the polar axis; ora round to lolongate, 4-6 μm long, often indistinct.

**Occurrence.** To 2% in 24 levels at San Miguel and 1% in one lignite from Lake Somerville.

**Range.** Upper Claibornian (Upper Lisbon Fm.) into the Oligocene (Frederiksen, 1988).

Araliaceoipollenites megaporifer Frederiksen 1980

Tricolporites sp. (?Araliaceoipollenites) Tschudy and Van Loenen, 1970, pl. 4, figs. 22a-b.

Araliaceoipollenites megaporifer Frederiksen, 1980a, pp. 52-53, pl. 11, figs. 31-32; pl. 12, fig. 1.

**Description.** Size 14-29 μm, mean 23 μm, holotype 26 μm. Tricolporate. Subprolate to prolate, mostly prolate; outline oval with rounded ends. Exine about 1 μm thick, columellate; sexine: nexine ratio 2:1. In some specimens the exine thickens from slightly less than 1 μm at the equator to more than 1 μm at the poles because of a thickening of the endosexine. Design granulate, surface rough. Colpi very narrow and extending from three-fourths of the grain to the full length; thickenings of the colpi margines 0.3 to 1 μm wide. Ora round, 2.5 - 4 μm in diameter, extending beyond the colpi margines.

**Occurrence.** To 3% in 21 samples from San Miguel and 1% in three lignites from Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a). Rouse and Mathews (1988) commented that the Araliaceoipollenites species "... are very widespread..." in Middle Eocene to Early Oligocene samples, "...extending into the Beaufort Sea in the north and offshore Labrador in the east. They are so characteristic of the Upper-Eocene interval off Labrador that Williams and Brideaux (1975) established the Araliaceoipollenites megaporifer Zone for the interval." (p. 1272)

## Genus Foveotricolporites Pierce 1961

### Foveotricolporites sp.

**Description.** Size 46-54 μm. Prolate; outline elliptical. Tricolporate; colpi narrow, extending nearly full length of grain; ora lolongate, 0.5-1.5 μm

wide; 0.5-3 μm deep, and 5-8 μm long. Exine 2 μm thick, tegillate, ectosexine:endosexine:nexine ratio 2:1:2. Foveolate, the fovelolae about 0.3 μm in diameter.

**Affinity.** Possibly Cornaceae, according to Frederiksen (1980a).

**Occurrence.** Less than 1% in three levels from San Miguel. Absent at Lake Somerville.

**Range.** Frederiksen (1980a) found this taxon only in the Oligocene Forest Hill Sand.

## Genus Ilex Linneaeus

**Affinity.** My grains of Ilex are very similar to modern species pictured in McAndrews et. al. (1978) and in the TAMU pollen reference collection. D. Taylor (written commun., 1988) believes that Ilexpollenites from the Claiborne "...appears to have affinities to Aquifoliaceae as previously suggested."

**Paleoenvironmental Notes.** Pflug (1957) found Ilex, in his study of German Upper Eocene brown coals, to be more common in clastics, and more likely to have come from lakeshore trees. Bartlett and Barghoorn (1973) noted that Ilex is not a prolific producer, and concluded that the presence of Ilex in Holocene sediments from Panama indicated proximity in the vicinity of the vegetational site. Furthermore, they felt that the occurrence of Ilex, a genus not presently growing in the sample area, signified a more seasonal climate than is present today on the Atlantic coast of the Canal Zone.

Van der Hammen (1963) found significant number of Ilex grains in his samples from British Guiana, hypothetically coming from species in swamp forest and marshwood.

Modern Ilex is a tree or shrub genus which contains 200 species in both hemispheres (Harrar and Harrar, 1962) and is widely distributed in both temperate and tropical areas (Li, 1972). Habitats are extremely variable.

One American species, Ilex decidua (winterberry) grows both on moist, rich upland soils and in swamps (Harrar and Harrar, 1962). In the Big Thicket of Texas, I. opaca (American holly) is found on well-drained ridges, whereas I. coriacea is an inhabitant of acid bogs (Ajilvsgi, 1979). Because of its ability to grow in wetlands, and its appearance in lignites (Hopkins, 1967; Rachele, 1976; Traverse, 1955), Ilex can be considered a probable indicator of wetland depositional environment.

Members of the Aquifoliaceae are largely insect pollinated, (Lewis et al., 1983; Lieux, 1983). Flenley (1979) points out that Ilex grains are of "medium/low relative export." Large concentrations of Ilex pollen in many samples from a site is unlikely. Pollen of this taxon is found in quantities to 50% of the pollen sum in upper levels of "treehouse" stratigraphies in the Okefenokee; surface samples show greatly reduced percentages in the adjacent marsh (Rich and Spackman, 1979).

**Occurrence.** "Undifferentiated" Ilex was tallied to 2% in 36 levels from San Miguel, and to 3% in seven lignite samples from Lake Somerville.

**Range.** According to Muller (1981), the first appearance of Ilex pollen is in the Turonian of Australia; Ilex first appears in the United States in the Cenomanian of California. During the Tertiary, Ilex distribution is cosmopolitan.

## Ilex infissa Frederiksen 1980

Ilex infissa Frederiksen, 1980a, p. 53, pl. 12, figs. 10-14.

**Description.** Size 19-28 μm, mean 24 μm, holotype, 28 μm. Prolate spheroidal to subprolate. Tricolporate; colpi narrow (0.5-1 μm wide), rather deeply invaginated, extending nearly full length of grain, bordered on each side by thickenings 2 μm wide; ora distinct, lalongate, slitlike, 0.5 μm wide and 3.5-5 μm long, cutting through marginal thickenings of the colpi. Exine 1.5-2 μm thick, sexine:nexine ratio 2:1, densely clavate, the clavae 1.3-2 μm long.

**Occurrence.** To 2% in 12 samples from San Miguel and 1% in one lignite from Lake Somerville.

**Range.** Found in the Jackson Group by Frederiksen (1980a).

## Ilex media (Pflug and Thomson) Frederiksen, 1980

Tricolporopollenites iliacus medius Pflug and Thomson in Thomson and Pflug, 1953, p. 106, pl. 14, figs. 46-60.

Ilexpollenites cf. I. iliacus (R. Potonié, 1931) Thiergart, 1937. Engelhardt, 1964, p. 73, pl. 2, fig. 22.

Ilexpollenites sp., Tschudy and Van Loenen, 1970, pl. 4, figs. 19, 18?

Ilex media (Pfleug and Thomson) Frederiksen, 1980a, pp. 53-54, pl. 12, figs. 15-16.

**Description.** 25-45 μm. Height of the "little clubs" (clavae) normally not under 1/12 of the maximum diameter of the grain, clavae smallest partly globeheaded. Diameter of globular heads mostly not under 2 μm. Clavae height mostly over 3 μm. Outline

globular to ellipsoidal. Exine regular with clavae sitting on it. [Translated from Thomson & Pflug]

**Range.** Members of the family Aquifoliaceae appeared during the Turonian. During the Tertiary, the family became widespread (Muller, 1981). Found by Frederiksen (1980a) in the Upper Claiborne to Lower Vicksburg.

**Occurrence.** Present in two samples from the San Miguel Sequence E at 3% and 10%. Absent at Lake Somerville.

## Genus Verrutricolporites van der Hammen and Wijmstra 1964

**Paleoenvironmental Notes.** Because of its distribution, Frederiksen (1981) believed pollen of Verrutricolpoites n. sp. to have come from plants more common outside of the peat-forming communities. One species, Verrutricolporites rotundiporis was compared by Germeraad et al. (1968) to the modern pollen of Crenea, which grows along water courses and swampy areas, and in the mangrove vegetation of tropical regions.

**Occurrence.** Undifferentiated Verrutricolporites is present to 2% in 10 samples from San Miguel and 1% in three lignites and the clastic sample from Lake Somerville.

### Verrutricolporites cruciatus Frederiksen 1980

Tricolporopollenites spp. Tschudy, 1973, p. B15, pl. 3, figs. 17-19?

Verrutricolporites cruciatus Frederiksen, 1980a, p. 54, pl. 12, figs. 17-19.

**Description.** Size 26-34 μm, mean 29 μm, holotype 31 μm. Prolate: outline oval with rounded to slightly pointed ends. Tricolporate; colpi narrow, extending about four-fifths the edge of the grain, edges thickened little or not at all; ora distinct, lalongate, 1-3 μm X 3-8 μm. Exine 1.5-2 μm thick including ornamentation; sexine:nexine ratio 1:1; verrucate, the elements irregular in design, about 0.5-1 μm in diameter and 0.3-0.5 μm high; negative reticulum rather well developed.

**Affinity.** Unknown

**Occurrence.** To 2% in 12 samples from San Miguel; in sequence H, where only Verrutricolpites spp. was tallied, there were two levels with less than 1%. At Lake Somerville, to 1% in three lignites and the clastic sample.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a).

Verrutricolporites ovalis (Potonié) Frederiksen 1980

Verrutricolporites ovalis (Potonié) Frederiksen 1980, p. 54, pl. 12, figs. 20-21.

Pollenites cingulum ovalis Potonié, 1934, p. 83, pl. 4, fig. 8.

Tricolporopollenites sp. 5. Engelhardt, 1964, p. 74, pl. 3, fig. 30.

Tricolpate rugulose-verrucose pollen. Fairchild and Elsik, 1969, pl. 37, fig. 18.

Unidentified tricolpate pollen having relatively coarse verrucos-rugulose ornament. Elsik, 1974, pl. 4, fig. 119.

**Occurrence.** 1% in one sample from San Miguel Sequence G. Absent at Lake Somerville.

**Range.** A few grains were found by Frederiksen (1980a) in Jackson and Vicksburg sediments.

Verrutricolporites tenuicrassus Frederiksen 1980

Verrutricolporites tenuicrassus Frederiksen, 1980a, p. 54, pl. 12, figs. 22-25.

**Description.** Size 23-34 μm (five specimens), holotype 31 μm. Prolate, outline oval. Tricolporate; colpi 0.5-1μm wide, extending nearly full length of the grain; ora lalongate about 3 X 6 μm. Exine 0.7-1.2 μm thick at equator and 2-3 μm thick at poles; sexine: nexine ratio 2-3.1; verrucate, the elements irregular in design. 0.5-1 μm in diameter and 0.2 -0.5 μm high; negative reticulum present; exine may be indistinctly tegillate.

**Affinity.** Possibly Fagaceae, according to Frederiksen (1980a)

**Occurrence.** To 2% in 12 samples from San Miguel.

**Range.** Found by Frederiksen (1980a) in the Lower Jackson.

Genus Nyssa Linnaeus

Nyssa kruschii (Potonié) Frederiksen, 1980

Pollenites kruschi Potonié, 1931, p. 4, fig. 11.
Tricolporopollenites kruschii (Potonié) Thomson and Pflug, 1953, p. 103, pl. 13, figs. 14-63.
Nyssapollenites cf. Nyssa accessorius (R. Potonié, 1934) R. Potonié 1950, Engelhardt, 1964, p. 74, pl. 3, fig. 33.
Tetracolporites sp., Engelhardt, 1964, p. 76, pl. 4, fig. 50.

Nyssa sp., Fairchild and Elsik, 1969, p. 84, pl. 37, fig. 16.

Nyssa kruschii (Potonié) Frederiksen, 1980a, pp. 54-55, pl. 13, fig. 1.

**Description.** 15-50 μm. Outline ± globular or secondary pearshaped. Unsculptured. Intrarugulate structure. All pores circular and circumscribed by the Caverna. [Translated from Thomson and Pflug].

**Paleoenvironmental Notes.** Megafossil evidence for Nyssa has often been in the form of endocarps (fruits) because, according to Eyde and Barghoorn (1963), most Nyssa foliage is without conspicuous identifying features. The presence of these fruits in the Brandon and Wilcox lignites, as well as in European brown coals, suggests that Nyssa was a member of the Paleogene peat forming swamp community. In the Brandon lignites, some fruit species were found only in the silt and not the lignite. Dilcher and McQuade (1967) described the endocarp N. eolignitica from Middle Eocene silts in Tennessee; they believed it to be similar both to the modern N. ogeche and the Oligocene N. lescurii from the Brandon silts.

A study of wood and pollen from the Miocene Rhenish brown coal by Van der Burgh (1967) yielded relatively equal proportions of pollen and fruits of Nyssa.

Nyssa pollen was common in a Yequa Fm. lignite located in fluvial strata in Madison County, Texas (Elsik, 1978) where it was considered "...indicative of a swamp environment. (p. 28)." A Yegua Fm. lignite from Brazos County, Texas which I have examined also yielded abundant Nyssa pollen.

Nyssa occurred preferentially in the lignite layers of the Oligocene Brandon Lignite deposit of Vermont. Values were to 5%, as opposed to 1.2% in the silts and

clays (Traverse, 1955). Clark (1986), in his study of the modern barrier beach vegetation of Long Island, used a minimum of 3% of Nyssa pollen to indicate a local presence in the form of a maritime forest community.

Frederiksen (1980c) reported modern Nyssa growing in humid subtropical, winter-dry tropical, and wet tropical(?) regions. Nyssa is, according to Harlow (1957), "...a typical swamp-forest tree, found as well along lake shores, but growing on drier sites when planted." (p. 259) In the North, it grows in wet or moist soils (Curtis and Bausor, 1943).

In the present-day Okefenokee Swamp, Nyssa occupies peat substrates which are more mineral-rich than those in which Taxodium flourishes (Fair-Page and Cohen, 1990). In the dismal swamp, N. sylvatica inhabits the full range of swamp environments, including the rarely flooded forest community and the most extensively flooded forest community. It dominates in the maple-gum community, where water levels fluctuate for 6 months out of the year. (Brown, 1990) N. aquatica rarely germinates when submerged, according to Huenneke and Sharitz (1990).

Nyssa is entomophilous (Lewis et al, 1983), but incidental shedding of pollen occurs.

**Occurrence.** To 44% in 102 levels from San Miguel and to 15% in 13 lignites and the clastic sample from Lake Somerville.

**Range.** Pollen of the Nyssaceae first appeared in the Paleocene (Tiffney, 1985).

## Genus Rhoipites Wodehouse 1933

### Rhoipites angustus Frederiksen 1980

Tricolporopollenites dolium (R. Potonié, 1931) Thomson and Pflug, 1953 [misidentified]. Engelhardt, 1964, pl. 73, pl. 2, fig. 21.

Tricolporopollenites kruschii (Potonié, 1934) Thomson and Pflug 1953. Elsik, 1968, p. 628, pl. 34, figs 3a-b only.

Rhoipites angustus Frederiksen, 1980a, p. 55, pl. 13, figs. 2-8.

**Description.** Size 24 to 32 μm, mean 29 μm, holotype 32 μm. Prolate spheroidal to prolate; outline oval to diamond shaped, poles rounded to somewhat flattened. Tricolporate; colpi about three-fourths the length of the grain and very narrow (sides of the colpi may be pressed together), exine not thinned along colpi so that colpi walls appear very thick; ora distinct, round, 2-2.5 μm in diameter, endannuli apparently lacking. Exine 1 μm thick, minutely reticulate.

**Affinity.** Frederiksen (1980a) listed Mastixia, Nyssa, and Rhus barclayi as possible related taxa. Wodehouse (1933), in defining the genus, noted that the species R. bradleyi was a perfect match with the modern species Rhus typhina (staghorn sumac). The five megafossil species of Rhus present in his Green River Formation were in agreement with this match.

**Paleoenvironmental Notes.** N. Frederiksen is less than secure with his identification of Rhoipites latus as Rhus. He (written commun., 1988) suggested that "...The [R. angustus] parent plant...lived in a low-stress environment (??)...From the ornamentation one would guess that it was insect pollinated, which means the plants must have been abundant if the grains are plentiful...this is all speculation." His thoughts on pollination are in general agreement with those of Wodehouse (1933), who believed R. bradleyi to be insect

pollinated and living in great abundance close to the site of deposition.

The controversial Rhus (sumac) is a shrub or small tree. Some species live in moist, rich soil; others in dry, rocky areas. (Vines, 1982) Species of Rhus pioneer in larger clearings of the uplands of the Texas Big Thicket. (Ajilvsgi, 1979).

Frederiksen (1980c) reported Rhus as living in summer-dry subtropical and/or semiarid, humid subtropical, winter-dry tropical, and wet tropical regions.

**Occurrence.** To 40% in 130 samples from San Miguel. To 23% in 12 lignites and the clastic sample from Lake Somerville.

**Range.** R. angustus was found in the Upper Claibornian to Lower Vicksburgian of the Gulf Coast by Frederiksen (1980a); Elsik describes this species as Tricolporopollenites kruschii from the Sabinian Rockdale Lignite of Texas. Matthewes and Rouse (1984) found R. angustus from Early to Early Middle Eocene of the Fraser River area, British Columbia. Similar Rhoipites species were described from the Middle Eocene of California (Frederiksen, 1983).

Rhoipites latus Frederiksen 1980

Tricolporopollenites sp 4 Engelhardt, 1964, p. 74, pl. 3, fig. 29.
Tricolpopollenites sp., Tschudy and Van Loenen, 1970, pl. 5, figs. 13a-b.
Tricolporites sp., Tschudy and Van Loenen, p. 70, pl. 5, fig. 1.
Tricoloporopollenites n. sp. B (Parthenocissus type). Tschudy, 1973, p. B17, pl. 4, figs. 18-19.

Rhoipites latus Frederiksen, 1980a, pp. 55-56, pl. 13, figs. 9-13.

**Description.** Size 34-44 μm, mean 39 μm, holotype 42 μm. Prolate; outline oval. Tricolporate; colpi deep, narrow, extending nearly full length of grain, bordered by thickenings 1.-2 μm wide,; ora distinct and round, slightly lalongate, 2.5-3.5 μm in the greatest dimension, wider than colpi and creating depressions in marginal thickenings. Exine exclusive of ornamentation 0.5-0.7 μm thick. Exine reticulate; muri coarsely clavate in cross section, clavae 1.5 μm high, thin baculae present between clavae; muri duplibaculate, 0.5-0.8 μm thick and wide; luminae polygonal to longitudinally elongate, 0.5-1.5 μm X 1-2.5 μm.

**Affinity.** Rouse (1977) noticed a resemblance to the Tileaceous tropical genus Triumfetta; Barnett (1989) used this name for her R. latus specimens. Tschudy (1973) believed that R. latus may have been related to the modern genus Parthenocissus.

**Paleoenvironmental Notes.** The Rhoipites latus pictured by Matthewes and Rouse (1984) from Canada is much more finely reticulate than Frederiksen's Gulf Coast specimens. These authors interpreted the climate of British Columbia in the Early Eocene to be warmer and more humid than at present.

No significant environmental data is available for Rhoipites latus. Because of its distribution in clastics, Frederiksen (1981) believed pollen of "Parthenocissus?" to have come from plants common in non-peat forming coastal areas.

Frederiksen (1980c) reported Parthenocissus as growing in summer-dry subtropical and/or semiarid, humid subtropical, and winter-dry tropical areas. Virginia creeper, common in eastern North America, is a woody

vine. Two species of Parthenocissus are found in moist soils throughout most of the eastern part of the United States (Gleason and Cronquist, 1963); P. heptaphylla is found in rocky canyons and on sandy soil in the Edwards Plateau (Powell, 1988).

**Occurrence.** To 4% in 64 samples from San Miguel and in 16 lignite and the clastic sample from Lake Somerville.

**Range.** Middle of the Early Claiborne Tallahatta Fm. through the Eocene-Oligocene boundary in Alabama and Mississippi (Frederiksen, 1988). Frederiksen (1980a) found R. latus in Gulf Coast samples of Upper Claibornian to Vicksburgian age. R. latus was present in rocks of Early to Late Eocene in South Central British Columbia and in Early to Middle Eocene in Arctic rocks (Rouse, 1977). Similar Rhoipites grains are also found from the Middle Eocene of Nevada (Wingate, 1983).

## Genus Horniella Traverse 1955

**Description.** Tricolporate pollen with long, wide longitudinal furrows that are as if they were lateral extensions of the longitudinal furrows. Reticulate sculpture with very high muri.

**Affinity.** Frederiksen (1983) noted that "Specimens with rather straight colpi have some resemblance to pollen of Xylosma (Flacourtiaceae), whereas specimens with arched colpi are similar to pollen of Styrax (Styracaceae)."

### Large Species Group

**Occurrence.** To 3% in 53 samples from San Miguel. To 10% in four lignites at Lake Somerville.

Small Species Group

**Occurrence.** To 7% in 73 samples from San Miguel. To 2% in seven lignites from Lake Somerville.

**Range.** Frederiksen found specimens of the genus in samples ranging from Late Claiborne to Early Vicksburg.

Genus Caprifoliipites Wodehouse 1933

Caprifoliipites tantulus Frederiksen 1980

Caprifoliipites tantulus Frederiksen, 1980a, p. 57, pl. 14, figs. 1-2.

**Description.** These grains match the description of Caprifoliipites micrireticulatus (Pflug and Thomson in Thomson and Pflug, 1953) Potonié, 1960, but they are only 14-19 μm in greatest dimension (holotype 14 μm) whereas the size of C. microreticulatus was given as 18-30 μm.

**Affinity.** Fredericksen (1980a) suggested that Caprifoliipites tantulus pollen is similar to that of Viburnum (Caprifoliaceae).

**Paleoenvironmental Notes.** C. tantulus was common to abundant in Frederiksen's (1981) Jackson age lignites; it was less abundant in his clastics. C. tantulus pollen was also found in one of Frederiksen's Late Claiborne samples; Jones and Gennett (1991) found a few C. tantulus grains in marine sediments from the Claiborne Stone City Fm.

Frederiksen (1981) believed these grains to appear zoophilous, but conceded that they could be transitional from zoophilous to anemophilous. He also believed that, due to their abundance in coal and patchy but wide

distribution in clastics that the C. tantulus plant was a heavy producer, in part anemophilous, and possibly shrubby or herbaceous.

Crepet (1985) mentions Viburnum-type pollen described from the Middle Eocene of France by Gruas-Cavagnetto (1978), and suggests "...Hymenoptera (wasp), Myophily (rodent), Ornitophily (bird)..." as possible pollination mechanisms for that taxon.

Harrar and Harrar (1967) reported about 100 species of Viburnum in the United States, occurring as both trees and shrubs. There are six species in the southeastern United States, all small trees. One species, V. rufidulum, grows in a variety of conditions, but attains its best growth on moist, rich alluvium. Another, V. prunifolium, is found more often at forest borders and is not so fond of moist conditions.

Frederiksen (1980c) reported Viburnum as growing in summer-dry subtropical or semiarid, humid subtropical, winter-dry tropical, and wet tropical regions.

**Occurrence.** To 12% in 104 samples from San Miguel and to 33% in 18 lignites from Lake Somerville.

**Range.** Middle of the Early Claiborne Tallahatta Fm. to the top of the Jackson Fm. in Alabama and Mississippii (Frederiksen, 1988).

## Genus Ailanthipites Wodehouse 1933

### Ailanthipites berryi Wodehouse

Ailanthipites berryi Wodehouse, 1933, p. 512, fig. 44.
Tricolporopollenites sp. 1. Engelhardt, 1964, p. 73, pl. 3, fig. 25.

**Description.** Generally ellipsoidal, but somewhat various in shape according to the degree of their

expansion, tricolporate with furrows long, almost reaching from pole to pole, furrow rim and pore rim conspicuous, projecting deeply inward. Exine reticulate, pitted with the pits elongate and linearly arranged, forming a sort of thumb print. Grains 20-25 μm. 1 μm broad and 26-30 μm long. Holotype 36-19.8-61.5.

**Affinity.** Frederiksen (1980a) suggests possible affinities with Anacardiaceae, Burseraceae, Leguminoseae, Sapindaceae, and Simaroubaceae. Wodehouse (1933) believed "...with a fair degree of confidence... (p. 512)" that it should be assigned to the modern genus Ailanthus, megafossils of which he reported in the Green River Flora.

**Paleoenvironmental Notes.** Wodehouse (1933) theorized that "...they are obviously insect borne, yet the occur in the shales in large numbers. Therefore, they should belong to a plant which grew abundantly near the place of deposition (p. 512)."

The only species of Ailanthus present in America today, the "tree of Heaven" is introduced from China. It is an extremely opportunistic, fast growing species which can live anywhere. Members of the Simaroubaceae are primarily entimophilous, but are also facultative anemophilous (Lewis et al., 1983).

**Occurrence.** To 3% in 50 samples from San Miguel. To 1% in seven lignites and the clastic sample at Lake Somerville.

**Range.** The known range on the Gulf Coast of Ailanthipites berryi is Upper Eocene to Lower Oligocene (Frederiksen, 1980a). Various species of Ailanthipites were also found by Frederiksen (1983) in Middle Eocene clastics in California.

## Genus Alangiopollis Krutzsch 1962

### Alangiopollis sp. Frederiksen 1981

**Description.** Size 42-46 μm. Oblate spheroidal to suboblate; outline more or less round. Tricolporate; colpi extend about two-thirds the distance to the poles, bordered by thickenings 1-2.5 μm wide; ora round, 4-10 μm in diameter. Exine excluding ornamentation 1 μm thick. Exine reticulate; muri clavate in optical section, clavae 1.5 μm high, muri 0.5 μm wide and duplibaculate; lumina 1-2 μm in diameter.

**Range.** Found in Jackson Group samples by Frederiksen (1980a).

**Affinity.** According to Frederiksen (1980a), Alangiaceae, probably Alangium.

**Occurrence.** To 2% in 23 samples at San Miguel. Absent at Lake Somerville.

## Genus Myrtaceidites Cookson & Pike 1954

### Myrtaceidites parvus Cookson and Pike 1954

Myraceidites parvus Cookson and Pike, 1954, p. 206, pl. 1, figs. 27-31.

Myrtaceidites parvus nesus Cookson and Pike, 1954, p. 206, pl. 1, figs. 29-31.

Myrtaceidites parvus anesus Cookson and Pike, 1954, p. 206, pl. 1, figs. 27-28.

Cupanieidites sp., Tschudy and Van Loenen, 1970, pl. 4, figs. 23-24.

**Description.** Grains small, 9-14 μm in equatorial diameter; amb subtriangular with convex sides; arci

present which may or may not enclose polar islands. Exine psilate, indistinctly patterned, or granular.

**Affinity.** Muller (1968) believed palynomorphs of this genus to be "in all probability pollen from Myrtaceae." (p. 22) Frederiksen (1983) noted that M. parvus is a heterogenous form species representing mainly genera such as Myrtus, Eugenia, and Calyptranthes as well as perhaps Ardisia in the Myrsinaceaea.

**Paleoenvironmental Notes.** Frederiksen (1981) noted that Myrteacidites is slightly more common in Eocene clastics than in lignites and that the palynomorph may represent a shoreline plant.

Along with Cupaniedites orthoteichus, Myrtaceidites parvus is one of the few palynomorphs described both from the Gulf Coast and from Late Eocene lignites from Australia (Milne, 1988). Although M. parvus is present in quantities up to 1.6% in the Australian deposit, four other species are present, and the genus Myrtaceidites totals over 10% of the palynomorphs in one sample. These lignites formed in a "predominantly non-marine" setting (p 286).

Crepet (1985) cited the occurrence of Myrtaceidites sp. (i.e. Eugenia-type pollen) in the Middle Eocene Lawrence Clay Pit of Tennessee, using this genus as an example of "Chiropterophily, Ornithophily, Melittophily." In other words, he believed the Myrtaceidites plant to have been pollinated by bats, birds, or bees.

One Myrtaceous plant common in the southeastern United States is Eugenia axillaris, which is found on sandy soils near salt water. Another species, Anamomis simpsonii is found on hammocks. Calyptranthese pallens grows in Florida on hammocks and coastal soils of coral origin (Harrar and Harrar, 1969).

Pollination of modern Myrtaceae species is largely zoophilous and only incidentally anemophilous (Lewis et al, 1983). Flenley (1979) noted that Myrtaceous grains exhibit "some relative export."

**Occurrence.** Less than 1% in 28 samples from San Miguel. Present to 2% in four lignites from Lake Somerville.

**Range.** Upper part of the Middle to Upper Claiborne Lisbon Fm. through the Eocene-Oligocene boundary in Alabama and Mississippi (Frederiksen, 1988). Grains of the family Myrtaceae have been found since the Santonian. The earliest occurrence in North America of Myrteacidites sp. is in the Mid-Eocene of Tennessee (Muller, 1968).

Genus Cupanieidites Cookson & Pike 1954 emend. Chmura 1973

Cupanieidites orthoteichus Cookson & Pike 1954

Cupanieidites orthoteichus Cookson and Pike, 1954, p. 213, pl. 2, figs. 73-78.
Duplopollis orthoteichus (Cookson and Pike) Krutzsch, 1959, p. 145.
Duplopollis myrtoides Krutszch, 1959b, p. 145, pl. 34, figs. 25-44; text-fig. 13.
Cupanieidites orthteichus Cookson and Pike, 1954. Engelhardt, 1964, p. 74-75, pl. 3, fig. 34.
Duplopollis sp., Fairchild and Elsik, 1969, p. 84, pl. 37, fig. 19.
Duplopollis sp., Tschudy and Van Loenen, 1979, pl. 4, figs. 25-27.

**Description.** Grains isopolar to subisopolar; amb sharply triangular with straight sides; arci prominent,

forming distinct polar island, equatorial diameter 20-30 μm. Sexine reticulate, mesh fine, somewhat indistinct.

**Affinity.** According to SEM studies by Taylor (in press), C. orthoteichus has affinities to the Cupanieae group of the Sapindaceae.

**Paleoenvironmental Notes.** Cupanieidites orthoteichus is one of the few taxa found both in the San Miguel and in the Late Eocene of Western Australia, where it was found in frequencies of less than 1% by Milne (1988). Berry (1924) assigned leaf macrofossils from the Jackson Group of Georgia to Cupanites.

Crepet (1985) cited the occurrence of Sapindaceaous Diplopeltis hueglii-type flowers from the Middle Eocene of Central America by Kemp (1976), and hypothesized "Melittophily" (bees) as the form of pollination. In Costa Rica, the three species of Cupania live in habitats including dry tropical, where C. guatemalensis lives as a shrub, wet tropical, moist tropical, moist premontane, wet premontain; where C. macrophylla and C. glabra are intermediate trees; and premontain rainforest, where C. macrophylla occupies a canopy niche (Holdridge et al).

According to Lewis et al. (1983), although modern-day Sapinaceae are insect pollinated, the anthers are exposed and some pollen grains may become wind-borne.

**Occurrence.** Present to 4% in 36 samples from San Miguel. To 1% in five lignites from Lake Somerville.

**Range.** Base of the Middle to Upper Claiborne Lisbon Group to the top of the Jackson Group in Alabama and Mississippi (Frederiksen, 1988). The genus Cupanieidites has been found as early as the Conacian (Muller, 1981).

Genus Gothanipollis Krutzsch 1959

## Gothanipollis cockfieldensis Engelhardt 1964

Gothanipollis sp. 1. Engelhardt, 1964, p. 75, pl. 3, figs. 35-37.

Gothanipollis cockfieldensis Engelhardt, 1964, p. 598-600, pl. 1, figs. 1-4.

Gothanipollis sp., Fairchild and Elsik, 1969, p. 84, pl. 37, fig. 20.

Gothanipollis sp., Tschudy, 1973, p. B16, pl. 4, fig. 4 only.

Gothanipollis cockfieldensis Engelhardt, 1964b. Frederiksen, 1980, fig. 59, pl. 14, fig. 16.

**Description.** Pollen grains, syncolporate; polar view triangular with concave sides and truncated recurved apices; equatorial view, lens-shaped; three colpi straight, distinct, united at poles with vestibulate ora located at apices; exine 1 μm thick, sculpture granulate, psilate near colpi. Size range from 18 to 25 μm.

**Affinity.** Frederiksen (1980, 1985) hypothesized Gothanipollis to be Loranthaceous. Taylor (in press) believed G. cockfieldensis to have similarities with large flowered Neotropical Loranthaceous grains. Jarzen (1978), working in the Paleocene, linked Gothanipollis with the loranthaceous genus Aetanthus. Habitat was cited as "northern Andes temperate forests at elevations of 2000 feet or more". It also resembles the Chilean genus Psitacanthus cuneifolius as pictured by Heusser (1971).

**Paleoenvironmental Notes.** Modern members of the Loranthaceae (mistletoe family) are commonly parasitic. Quaternary pollen studies, for example that of Watts and Bradbury (1982), show that Loranthaceous pollen, usually that of the pine-dependent Arceuthobium, is found in

sediments near the place in which the host was growing. In their study of an Oligocene pollen flora from British Columbia, Rouse and Matthews (1979) found pollen from an apparently parasitic Gothanipollis plant associated with Taxodium, Metasequoia, and Juglans.

Crepet (1985) cited Loranthaceous pollen found in North-central Europe and Germany by Krutzsch (1970). He hypothesized "Melittophily (bees), Myophily (flies), Ornithophily (birds), Phalaenophily (marsupial flying squirrels)" as pollination mechanisms.

**Occurrence.** Present to 1% in four samples from San Miguel. Absent from Lake Somerville.

**Range.** Base of the Uppermost Claiborne Gosport Fm. to the top of the Jackson Group in Alabama and Mississippi (Frederiksen, 1988). Gothanipollis appears in both Gulf Coast and Central European sediments from the Middle Eocene (Fairchild and Elsik, 1969); Elsik (1978) found the taxon from the base of the Lower Eocene to the top of the Upper Eocene in Gulf Coast sediments, but the range extended into the Paleocene and Oligocene in the Pacific Northwest. Gothanipollis is also reported from the Middle Eocene Mission Valley Formation of California (Frederiksen, 1983), as well from the Middle Eocene of south central British Columbia (Rouse, 1977). The genus is missing from Wingate's (1983) Nevada flora, and has not, according to Rouse (1977), been found in any Arctic horizons.

Genus Bombacacidites Couper 1960 emend. Krutzsch 1970

Bombacacidites nacimientoensis (Anderson) Elsik

Bombacacidites nacimientoensis Anderson 1960, p. 23, pl. 8, fig. 15.

Bombacacidites nacimientoensis (Anderson 1960) Elsik, 1968, p. 620, p. 22, figs. 1-2, 4.

Bombacacidites sp., Tschudy and Van Loenen, 1970, p. 5, figs. 17-19.

**Description.** Oblate, tricolpate pollen with short wide furrows bordered by a wide margo; furrows reaching about one-half the distance to the pole; shape intersemiangular in polar view, the poles slightly protruding; sculpture reticlulate, with narrow and probably clavate, muri in the polar region; reticulum transitional into clavate sculpturing at the periphery.

**Affinity.** Probably Bombacaceae, according to Frederiksen (1981). Westgate and Gee (in press) suggested an affinity to the Bombacaceae-Sterculiaceae-Tiliaceae complex for the similar B. paulus. Elsik (1968) listed the Bombacaceae or Tiliaceae as possible affinities. Taylor (1988) noted a close resemblance to the Bombax clade.

**Paleoenvironmental Notes.** Westgate and Gee (in press) proposed that the Bombacacidites paulus in their South Texas Middle Eocene lignite might be from a plant similar to the back mangrove and forest tree Brownlowia or to several genera of the Bombacaceae which are pantropical rain forest trees.

Berry described leaf fossils of Bombacites jacksoniana from the Jackson Group near Somerville, Texas and from the Fayette Sandstone in Webb Co., Texas.

Bartlett and Barghorn (1973) illustrated a similar palynomorph from the extant neotropical plant Pseudobombax septenatum, which occurs on forested hills, in pastures, and along roads, usually on sandy soil. Pseudobombax pollen was present in only one of four modern surface sediment samples from Gatun Lake in Panama, and the authors believed the pollen

"...undoubtedly came from a large tree of this genus growing in the vicinity of the sampling site." (p. 227) Van der Hammen (1963) mentioned that the Bombacaceae may occur in rain and marsh forests, in swamp woodlands along river banks, and also in savannas.

**Occurrence.** Absent at San Miguel. 1% in one lignite from Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a).

Genus Intratriporopollenites Pflug & Thomson in Thomson & Pflug 1953

Intratriporopollenites stavensis Frederiksen 1980

Tiliaepollenites sp., Engelhardt, 1964, p. 77, pl. 4, fig. 48.

Tiliaepollenites sp., Tschudy and Van Loenen, 1970, 1970, pl. 5, figs. 13, ?11a-b, ?14-15.

**Description.** Size 16-31 μm, mean 25 μm, holotype 24 μm. Tricolporate, rarely tetracolporate. Peroblate; outline rounded triangular, occasionally nearly round. Exine 1 μm thick including ornamentation; sexine: nexine ratio 2-3.1. Sexine reticulate, the muri about 0.3 μm wide and slightly clavate in optical section, rising 0.5 μm or less above exine surface. Lumina polygonal, about 1 μm in diameter, with a small granum in the center of each lumen. Sexine slightly overhangs apertures; colpi and ora 1-2 μm wide at equator; reticulum extends to edges of apertures. Nexine at the apertures thickens perpendicular to sexine; nexine (endannulus) 1.5-2.5 μm thick around vestibula, thinning slightly toward bases of vestibula.

**Affinity.** Bombacaeae-Sterculiaceae-Tiliaceae complex (Frederiksen, 1973).

**Paleoenvironmental Notes.** From its distribution, Frederiksen (1981) believed Intratriporopollenites n. sp. to have come from plants abundant on the Gulf Coastal Plain, but living mainly or entirely outside the "deltaic" swamp. Fechner (1988) and Mohr and Fechner (1986) hypothesized the similar I. ceciensis from the Middle Eocene of North Africa to represent the Tiliaceous mangrove Brownlowia, which is not restricted to tropical coastal environments.

Berry (1924) described macrofossils of Tilia jacksoniana from the Fayette sandstone, near Wellborn, Brazos Co., TX.

The Tiliaceae is described by Lewis et al. (1983) as primarily a tropical woody family with some native North American species. The flowers often secrete a sweet scent and nectar, with entomophily by bees, flies, and moths. Tilia pollen is produced in large quantities and is found in the pollen rain at substantial distances from the source.

**Occurrence.** Present at less than 1% in five samples from San Miguel and at 6% in one lignite from Lake Somerville.

**Range.** Lower Claiborne Tallahatta Fm. through the Eocene-Oligocene boundary in Alabama and Mississippi (Frederiksen, 1988).

## Genus Reticulataepollis Krutzsch 1959

### Reticulataepollis reticlavata Frederiksen 1980

Reticulataepollis reticlavata Frederiksen, 1980a, p. 60, pl. 14, figs. 23-26.

**Description.** Size 16-30 μm, mean 23 μm, holotype 23 μm. Tricolporate. Oblate; outline rounded triangular. Exine 0.05 μm thick; the muri coarsely clavate in optical section, muri 0.5-1 μm thick; clavae 1.5-2 μm high, projecting slightly above muri; muri 1 μm wide, lumina 1.5-2.5 μm in diameter. Colpi boat shaped, 5.5 μm long and 1 μm wide; ora 1-1.5 μm in diameter, endannulus 3-5.5 μm in diameter.

**Affinity.** According to Frederiksen (1980a) similar to Kirkia and Ligustrum.

**Occurrence.** 1% from one sample from Sequence A from San Miguel. Absent at Lake Somerville.

**Range.** Upper Claiborne to Lower Jackson (Frederiksen, 1980a).

## Genus Symplocos Jacquin

**Occurrence.** Undifferentiated Symplocos sp. is present at less than 1% in 6 samples from San Miguel and in 2 samples from Lake Somerville.

## Symplocos contracta Frederiksen 1980

Symplocoipollenites sp. 1. Engelhardt, 1964, p. 75, pl. 4, fig.39.

Triporopollenites sp., Tschudy and Van Loenen, 1970, pl. 3, fig. 13.

Porocolpopollenites spp., Tschudy, 1973, p. B15, pl. 3, figs. 5-6.

Symplocos contracta Frederiksen, 1980a, p. 61, pl. 15, figs. 6-9.

**Description.** Size 22-34 μm, mean 28 μm, holotype 32 μm. Peroblate; outline triangular with straight to slightly convex. Tricolporate. Exine finely foveolate

and tegillate; midway between apertures it is 1.5-2 μm thick, Nexine 0.5 μm, endosexine 0.71 μm, ectosexine 0.7-1 μm, ectosexine 0.3 to 0.5 μm; sexine thins gradually towards apertures, where it is 0.3-0.5 μm thick. Colpi 1-2.5 μm long lacking marginal thickenings; ora obscure; vestibula 0.5 μm or less deep, typically slitlike in optical section.

**Affinity.** Frederiksen (1980a) cites the opinion of many authors that no modern genera other than Symplocos have pollen of the Porocolpopollenites-Symplocoipollenites type.

**Paleoenvironmental Notes.** Fossil Symplocos pollen has been found in the Brandon lignite (Traverse, 1955) and the Eocene German brown coals, where the plant apparently lived in coastal swamps (Frederiksen, 1981).

The modern genus Symplocos, or sweetleaf, is usually seen as a shrub, but occasionally as a tree. It is found in the West Indes, Asia, and Australia, and in the United States ranges from Delaware to Florida west to eastern Texas and Arkansas (Harrar and Harrar, 1962). Symplocos habitats range from coastal plains to mountains; it lives in swamps and stream margins, in sandy thickets, in alluvial woods, in rich, moist forest soils, and in upland areas (Frederiksen, 1981; Harrar and Harrar 1962). Frederiksen (1980c) classified the climatic range of Symplocos as humid subtropical, winter dry tropical, and wet tropical. The family is insect pollinated (Machin, 1971).

**Occurrence.** Present at less than 1% in 6 samples from San Miguel. Absent from Lake Somerville.

**Range.** Upper Claiborne and Lower Vicksburg (Frederiksen, 1980a).

Symplocos gemmata Frederiksen 1980

Symplocoipollenites sp., Tschudy and Van Loenen, 1970, pl. 5, figs. 6 a-b.

Porocolpopollenites spp., Tschudy, 1973, p. B16, pl. 4, figs. 8-9.

Symplocos gemmata Frederiksen, 1980a, p. 61-62, pl. 15, figs. 10-14.

**Description.** Size 19-31 μm, mean 26 μm, holotype 29 μm. Tricolporate. Oblate; outline triangular with strongly convex to nearly straight sides. Exine 1 μm thick, sexine:nexine ratio 2:1 except at apertures. Sexine indistinctly tegillate and rather sparsely to densely gemmate to granulate, the elements typically varying in size on each specimen, from 0.3 to 1.5 μm in diameter and to as much as 1 μm in height. Ornamentation covers entire exine up to edge of apertures. Colpi 0.5-1 μm wide at the equator, narrowing rapidly away from the equator; colpi very short, usually not extending past the endannulus, often barely visible so that some grains look triporate; colpi may be bordered by narrow (0.5-μm-wide), smooth margins which wrap around the ends of colpi. Shallow vestibula present. Endannuli 2-3 μm thick, with ora about 2.5 μm in diameter; sexine does not thicken at apertures.

**Occurrence.** Present at less than 1% in four samples from San Miguel. Absent at Lake Somerville.

**Range.** Middle Claiborne Lisbon formation to the top of the Jacksonian in Mississippii and Alabama (Frederiksen, 1988).

## Symplocos jacksoniana Traverse 1955

Symplocos jacksoniana Traverse 1955, p. 73, fig. 13.

Symplocoipollenites jacksonius (Traverse) Potonié, 1960, p. 107.

Proteacidites sp., Engelhardt, 1964, p. 75, pl. 4, fig. 41.

Symplocoipollenites sp., Tschudy and Van Loenen, 1970, pl. 5, fig. 9.

**Description.** Tricolporate pollen grain of distinctive triangular shape as seen in polar view. Longitudinal furrows very short, scarcely visible in the polar views. Transverse furrows also short and narrow. Conspicuously distinct ektexine and endexine. Sculpture pitted, similar to that of S. paniculata Wall. Columellate tectum. Costae, mostly transverse, under furrow. Size: ca. 24 μm. (Grains have very short polar axes-always present in polar views.) Thickness of exine: ca. 2 μm.

**Occurrence.** Present in two samples from San Miguel; absent at Lake Somerville.

**Range.** Symplocos jacksoniana appears in the Middle Claiborne Lisbon Fm. on the Eastern Gulf Coast and occurrences continue through the Eocene-Oligocene boundary (Frederiksen, 1988).

## Symplocos tecta Frederiksen 1980

Tricolporopollenites sp. 7. Engelhardt, 1964, p. 74, pl. 3, fig. 32.

Symplocos tecta Frederiksen, 1980a, p. 62, pl. 15, figs. 17-20.

**Description.** Size 24-36 μm, mean 31 μm, holotype 34μm. Oblate or peroblate; outline rounded triangular. Tricolporate; colpi extend one-third to one-half the distance to poles, not bordered by thickenings; vestibula shallow, often slitlike in optical section, sometimes covered by folds; ora obscure in polar view. Exine 3-4 μm thick midway between apertures; tegillate,

ectosexine:endosexine:nexine ratio about 2-4:1:1; sexine thins toward apertures. Exine infraverrucate, elements 0.5-1 μm wide; very fine negative reticulum present.

**Affinity.** Frederiksen (1980a) believed this taxon to be similar to modern pollen of Symplocos glauca.

**Occurrence.** One specimen from Sequence E of San Miguel; absent at Lake Somerville.

**Range.** S. tecta ranges from the base of the Jackson into the Oligocene in Mississippi and Alabama. The range top is not known (Frederiksen, 1988).

## Symplocos arcuata Frederiksen 1980

Symplocoipollenites sp., Fairchild and Elsik, 1969, p. 84, pl. 37, fig. 15.

Symplocos arcuata Frederiksen, 1980a, p. 60-61, pl. 15, figs. 1-4.

**Description.** Size 26-30 μm (six specimens), mean 28 μm. Oblate or peroblate; outline triangular with convex sides. Tricolporate, colpi extending about one-third the distance to the poles, not bordered by thickenings; ora obscure in polar view; vestibulum split shaped in optical section because both nexine and sexine are arched outward at the apertures. Exine 1 μm thick excluding ornamentation, weakly tegillate, sexine:nexine ratio 1.5:1, at the apertures, sexine is about 1.3 μm thick and nexine 1 μm thick; thickening of exine at apertures (tumescence) produces darker exine color in aperture region. Exine rugulate to verrucate, elements 0.5 μm wide and 0.2-0.5 μm high; no negative reticulum present.

**Occurrence.** One grain from San Miguel in Sequence F; absent at Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a)

## Genus Tetracolporopollenites Pflug & Thomson in Thomson & Pflug, 1953

**Description.** Normally four pores (in rare cases, also three). These sit symmetrically in relation to each other. Pores with meridional colpi and equatorial pores (?). Polar axis is squarish (in rare cases triangular), symmetrical.

**Affinity.** Based on a study of the Sapotaceae by Harley (1986), Taylor (1989) decided that the grains of Tetracolporopollenites brevis from the Claiborne Group of Tennessee belonged to Group B of this family. According to Taylor, "The fossil pollen is similar to this extant pollen group in which are found the subfamilies Mimusopsioideae and Madhucoideae. The fossil grains are not identical to the pollen grains of any extent genus and may be from an extant lineage or taxon within the family." (no page)

**Paleoenvironmental Notes.** Anderson and Muller (1975) mentioned palynomorphs designated as "Palaquium-complex" in their Quaternary pollen flora from Borneo. These grains include sapotaceous genera from both coastal areas and peat swamp forest.

Sapotaceous megafossils were described by Berry (1924) from the Fayette Sandstone of Webb, Grimes, Fayette, and Brazos Counties, Texas. The specimen from the last location was compared to the modern genus Mimusops.

Mimusopsis is a Paleotropical genus. The closely related genus Manilkara comprises tree and shrubs; there are thirty Neotropical species. M. inundata is found on

swampy ground below 200 m. in the lowland rainforests of Amazonia; it is particularly frequent on periodically or permanently flooded sites. Two species grow on periodically flooded ground. Most species, however, prefer dry land. One species, M. jaimiqui, grows in coastal scrublands and thickets in Florida, often in association with mangroves. (Pennington, 1990).

Very little is known about the pollination mechanisms of the Sapotaceae. Some are pollinated by bats. Pennington (1990) assumed that individuals would be visited by bees, insects and larger animals because of the floral structure and the tasty nature of the corolla.

**Occurrence.** Present to 10% in 41 samples from San Miguel and to 2% from eight lignites from Lake Somerville.

**Range.** Upper Claiborne to Lower Vicksburg (Frederiksen, 1980a).

## Genus Ericipites Wodehouse 1933

### Ericipites redbluffensis Frederiksen 1980

**Description.** Size of tetrad 27-32 μm, mean 29 μm, holotype 29 μm. Distinct notches present in outline of tetrad where grains meet. Individual grains more or less spheroidal; outline of grain in polar view triangular with concave to convex sides. Tricolpate with definite geniculi and probably no ora, colpi extending near full length of grain or sometimes syncolpate. Colpi of adjacent grains probably meet fundamentally according to Fischer's rule, but because the grains are syncolpate or nearly so,, colpi of all four grains meet at the center of the tetrad. Exine 1

μm thick, tegillate, ectosexine: endosexine: nexine ratio 1:2:1; sharply infragranulate to finely infraverrucate; outline rough.

**Affinity.** Frederiksen (1980a) gave the affinity of Ericipites as "Ericaceae?" (p. 65). The tetrads are also very similar to pollen extracted from Eomimosoidea plumosa Crepet and Dilcher, a fossil Leguminosae (Mimoisoideae) flower described by Crepet and Dilcher (1977) from the Middle Eocene of Tennessee. These palynomorphs, placed in the form genus Ericipites, consist of tetrads about 32 μm in diameter. Herendeen and Dilcher (1990) added that the flower most closely resembles the genera Dinizia and Fillaeopsis belonging to the tribe Mimoseae. According to Herendeen and Dilcher, leaves and fruits which co-occur with the inflorescence also resemble Dinizia in many respects.

**Paleoenvironmental Notes.** Van der Burgh (1967) found pollen of Ericaceae but no wood in his Rhenish brown coals. In the same deposit, wood but no pollen of Leguminosae was present.

Wolfe (1978) pointed out that the Late Claiborne assemblages from Tennessee contains diverse Leguminoseae (Fabaceae) macrofossils. It was significant to him that the family is common in dry tropical vegetation today. Additionally, Berry (1924) described fossils of the genus Mimosites in the Jackson age Fayette sandstone from near Wellborn, Brazos Co., TX.

Crepet (1985) suggested "Chiropterophily (bats), Melittophily (bees), Ornithophily (birds)" as possible pollination mechanisms for Eomimosoidea plumosa, based on the brush type flowers of both that species and modern Mimosoids.

**Occurrence.** Present to 1% in 25 samples from San Miguel. Absent at Lake Somerville.

**Range.** Frederiksen (1980a) found E. redbluffensis from the upper part of the Claiborne into the Oligocene.

## Genus Aesculidites Elsik 1968

### Aesculiidites circumstriatus (Fairchild) Elsik 1968

Aesculiidites circumstriatus (Fairchild) Elsik, 1978, p. 632, pl. 27, fig. 10-18; pl. 28, fig. 1-7.
Tricolpites circumstriatus Fairchild in Stover, Elsik, and Fairchild, 1966, p. 5, pl. 2, fig. 3-7.

**Description.** Pollen isopolar, slightly prolate, spheroidal. Colpi long, extending almost to the poles. Exine less than 1 μm thick, layering not distinguishable. Colpi margins slightly thickened in the equatorial area, in some with rudimentary transverse furrow. Sculpture consists of minute irregular striations more or less parallel to equatorial plane. In polar view, striations appear roughly concentric around pole. Size range; equatorial diameter, 14 to 16 μm; length 18 to 22 μm based on 21 specimens.

**Occurrence.** 1% in one sample from Sequence B at San Miguel; absent from Lake Somerville.

**Range.** Elsik (1968) found this taxon in the Paleocene Rockdale lignite.

# BIOSTRATIGRAPHY

It is possible to date sedimentological units using both dominant and indicator palynomorphs. For Pre-Quaternary samples, both methods rely on comparisons with well dated palynomorph assemblages. The ages of these assemblages are based on the ages of paleozoological or microplaeontological assemblages from the same beds (Tschudy and Scott, 1969).

The concept of dominant types involves comparison of percentages or absolute numbers of palynomorphs (Tschudy and Scott, 1969). The method has been incorporated by Quaternary palynologists (Moore and Webb, 1978) into correlations of lake sediments; regional climatic or anthropogenic events which affected vegetational patterns are used as time markers. Pre-Quaternary researchers have also used the technique. Tschudy and Scott (1969) cautioned that the dominant forms may differ with climate or edaphic changes, especially in coals. Entomophilous taxa are more likely to be facies dependent, but, due to low palynomorph production in entomophilous plants, these taxa rarely dominate an assemblage. Wind-pollinated types are more likely to be abundant and represent a regional pollen rain which is not facies dependent.

The method utilizing indicator taxa is based on the origination and extinction of palynomorph taxa (Tschudy and Scott, 1969). Correlations are most reliable when the samples do not contain reworked grains, when an adequate number of grains are examined, and when the indicator taxa are relatively abundant regionally. These indicator taxa may be also be facies

dependant, and presence of a particular palynomorph is more important than absence. Gulf Coast ranges for Eocene palynomorphs are well studied and were published by Elsik (1974) and Frederiksen (1988). Most palynological correlation utilizes both techniques.

Lake Somerville Spillway

Very little formal work has been published on the Spillway section at Lake Somerville. The site was mapped as Manning Fm. (Jackson Group) by The Texas Bureau of Economic Geology (1974) and is within the Fayette Paleodelta described by Fisher et al. (1970). Most of the palynomorph spectra from Lake Somerville are comparable to those described by Frederiksen (1981) from the Gibbons Creek lignites from Grimes County, designated as Manning Fm. (Jackson Group) and which may correlate with the Lake Somerville lignites (Yancey and Davidoff, 1991).

In most samples from both sites, Momipites coryloides dominates and Caprifoliipites tantulus is an important taxon. Samples from both sites also lack palynomorphs restricted to the Middle Eocene and the high percentages of the oaklike genus Quercoidites common in the Early Oligocene.

Compared to the samples from Lake Somerville, the samples from Gibbons Creek examined by Frederiksen vary less in palynomorph content and no samples from Gibbons Creek have high percentages of Cupuliferoipollenites or spores. These taxa dominate the samples from the seam bases and tops at Lake Somerville. Although never important in the lignites at Gibbons Creek, Cupuliferoipollenites is sometimes common in other

Jackson Group lignites. For example, abundant Cupuliferoipollenites occurs in clastic samples of Jackson age from Mississippi (Frederiksen, 1981).

Frederiksen analyzed only a few samples to characterize each seam and this sparse sampling may be responsible for the lack of variability at Gibbons Creek. My analysis of additional Gibbons Creek material provided spectra different than those presented by Frederiksen: one sample was dominated by palm (Arecipites) pollen and contained very little Momipites, and another yielded a high percentage of Chrysophyllum brevisulcatum (Gennett et al., 1986; unpublished data). Given the possible influences of sampling technique, the palynomorph floras are not significantly different at the two sites, and the Lake Somerville Spillway spectra are consistent with the assignment of these lignites to the Manning Fm. (Jackson Group).

The San Miguel Deposit

**Stratigraphy and Biostratigraphy.** Snedden (1979) summarized the various opinions on the stratigraphic position of the San Miguel lignites. Early investigators (Duessen, 1924; Lonsdale, 1935; Halbouty, 1931; Maxwell, 1962) placed the San Miguel seams in the Yegua Fm. (Claiborne Group) based on stratigraphic position, and Fisher (1963) believed the San Miguel lignites to be similar to Yegua lignites found in water wells drilled in southern Atascosa County. However, Kaiser (1974) placed the San Miguel within the Jackson Group based on its position in a subsurface log above a shale marker identified as the Cadell Fm., which locally forms the base of the Jackson Group. A revised map by

the Texas Bureau of Economic Geology (1974) placed the mine itself well within the Jackson Group.

Snedden attempted to place the San Miguel lignites stratigrapically using the macrofauna, but encountered difficulties with regional correlation and environment of deposition. He identified only one bivalve taxon, Rhabdopitaria, in his cores. This genus is present in the Eocene section only as far up as the Gosport Fm. (Late Claiborne). Unfortunately, the Rhabdopitaria individuals found by Snedden could not be placed in any known species within the genus. The most abundant gastropod in the San Miguel cores, Bittium (Stylidium) elegans, is also found in the Gosport Fm. (Late Claiborne) of Alabama. Snedden's biostratigraphic evidence suggested, but did not prove, a Late Claibornian age for the San Miguel lignites.

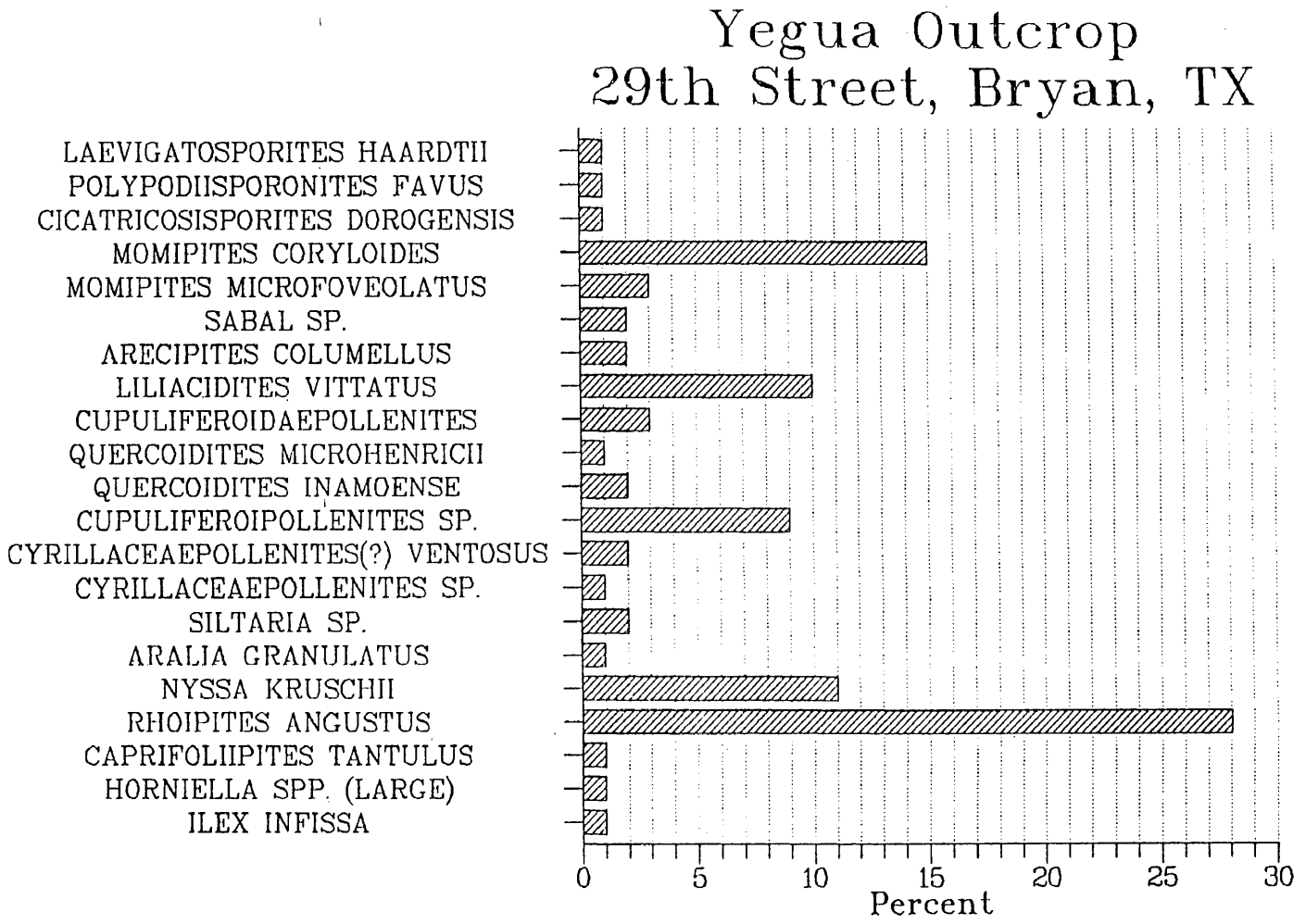
**Dominant Taxa.** The San Miguel lignites are dominated by small tricolporates, notably Cupuliferoipollenites, but also Siltaria and Araliaceoipollenites granulatus. These lignites are easily distinguished from the Lower Claiborne lignites of the Rio Grande Valley described by Martinez-Hernández et al. (1980) and Mukhopadyay (1989). In those Early Claiborne samples, tricolpates and tricolporates from taxa other than Cupuliferoipollenites, Siltaria, and Araliaceoipollenites granulatus were the most important taxa.

It is difficult to place the San Miguel lignites within the Middle to Upper Claiborne and Jackson Groups on the basis of dominant palynomorphs. No complete spectra for Claiborne lignites are available from Texas, and only two are available from Mississippi (Frederiksen, 1981). Some samples from the San Miguel lignites are similar in palynomorph composition to the

Middle Claiborne samples from Mississippi, but differ in that the latter contain larger percentages of Quercoidites microhenricii. This fagaceous taxon is, however, common in a few San Miguel lignite samples.

The Middle Claiborne lignite samples lack Caprifoliipites tantulus, a pollen type which is consistently present in the San Miguel lignites and which is a co-dominant in some Jackson Group lignite samples (Frederiksen, 1981; Elsik, 1978). However, this taxon was present, but rare, in clastic samples from the Middle Claiborne Eocene Stone City Fm. (Jones and Gennett, 1991), and a more extensive survey of Middle Claiborne lignites could yield samples containing Caprifoliipites. The consistent appearance of C. tantulus within the San Miguel samples suggests an affinity with the upper Claiborne or the Jackson Group.

The lignite from Late Claibornian (=Yegua Fm.) Miller Clay pit (Potter, 1976) offers spectra dominated by Cupuliferoipollenites in percentages similar to those from most of the San Miguel spectra. Difficulties arise in equating the San Miguel with the Miller Clay pit. Firstly, the series of fossil oxbow lakes in which the Miller pit is located was dated using primarily palynological techniques. But more importantly, the clay pit is located hundreds of km. to the east of the San Miguel lignites and represents a different depositional environment. The few analyzed samples of Late Claibornian lignites from the Mississippi Cockfield (=Yegua) Fm. (Frederiksen, 1981) and from the Yegua Fm. of Texas (Text-Figure 20; Elsik, 1978) have pollen spectra dominated by Momipites and sometimes co-dominated by Nyssa and Rhoipites angustus. These Late Claiborne lignites are actually more similar in dominant palynomorph composition to the Jackson age lignites




Text-Figure 20. Pollen spectrum from a Yegua lignite, collected at 29th Street and Carter Creek Parkway, Bryan, TX.

from Lake Somerville and from the Gibbons Creek mine in Grimes County than they are to the San Miguel lignites.

Momipites is the most important taxon in all of the Jackson Group lignites which have been described (Table 2). Most of these lignites, including those from Lake Somerville and Gibbons Creek, were deposited in fluvio-deltaic environments at sites encompassed by the Fayette Paleodelta system (Frederiksen, 1981). Momipites was also the most important taxon in Jackson Group lignites from Miguel Aleman in northern Mexico which formed in a marginal marine system (Martinez-Hernández et al., 1980) beyond the direct influence of the Fayette Paleodelta. A "Yegua-Jackson" lignite from Zapata Co., TX, analyzed by Elsik (1986) also contained common to abundant Momipites. Like the San Miguel deposit, the Zapata Co. lignite also formed within the South Texas Strandplain-Barrier Bar System of Fisher et al. (1970). It has been suggested by various authors that all of these lignites may have formed in at least a brackish environment (Frederiksen, 1981; Mukhopdyay, 1989; Elsik, 1978).

Of the Late Claibornian and Jacksonian lignites, only the Late Claibornian Miller Clay Pit samples share an overall dominance of Cupuliferoipollenites with the San Miguel lignites. If only Cupuliferoipollenites were considered, it would be seem judicious to assign the San Miguel a Late Claibornian or "Yegua" age. However, these two sites differ in subdominant taxa. Whereas Momipites percentages are always less than 15% in the Miller Clay Pit lignite samples, this genus co-dominates with Cupuliferoipollenites in most of the spectra from the San Miguel F Core, and in spectra at the base of the C seam in core D. This corresponds to the sequence at Lake Somerville, where, although Momipites is dominant in most of the samples, Cupuliferoipollenites is the

most important palynomorph at the top of seams. Nyssa and Rhoipites are more numerous than Cupuliferoipollenites at the base of the C Seam in most cores, suggesting an affinity with the Yegua lignite sample from Brazos County. Secondly, as will be discussed in the next section, the overall floral composition of the lignites from the Late Claibornian Miller Pit and the San Miguel mine is quite different.

**Indicator Taxa.** At least one biostratigraphically important palynomorph strongly suggests that the San Miguel deposit is not Middle Claibornian in age. Nuxpollenites, a Mid-Claiborne indicator taxon (Elsik, 1974) is not present in the San Miguel lignites. Jones and Gennett (1991) indicated that this Mid-Claiborne indicator taxon is present in clastics from the Middle Claibornian Stone City Formation of East Central Texas. Considering the absence of this taxon, as well as the fact that dominant taxa and stratigraphic indicators suggest a "Yegua-Jackson" age, it is unlikely that the San Miguel is Middle Claibornian in age, but rather Late Claibornian or Jacksonian.

The palynoflora from the Late Claibornian Miller Clay pit contains some taxa which are not present or are very rare in the San Miguel lignite. One rare, but persistent taxon, Aesculdiites variabilis, reported by Potter (1976) from the Miller Pit lignite, was described by Nichols (1970) from Paleocene age Wilcox Group lignites. No grains of the genus Aesculiidites were found in the Upper Claiborne or Jackson clastics described by Frederiksen (1981, 1988). Only one grain of Aesculiidites was found in the San Miguel samples; this grain could have easily been reworked. W. Elsik (1974; written commun., 1992) reported that Nudopollis terminalis (=Extratriporopollenites terminalis) reaches

its peak abundance in the Upper Claiborne, and that it is present in the Yegua Fm. of Brazos Co., TX. N. terminalis (=Extratriporopollenites terminalis) is consistently present in percentages up to 3% in the Miller Pit lignite. No grains of N. terminalis were recovered from the San Miguel clastics or lignites. N. terminalis was also absent from a Late Claibornian lignite sample from Hinds Co., Mississippi (Frederiksen, 1981), and from three lignite samples briefly examined from the Yegua Fm. of Madison Co., TX by W. Elsik (1978; written commun., 1992). However, Elsik attributed the lack of N. terminalis in the Madison County lignite to the low number of palynomorphs examined. Finally, Anacolosodites efflatus was found consistently in samples from the upper part of the Miller Pit lignite. Anacolosidites was also noted by W. Elsik (written commun., 1992) in the Yegua lignite from Madison County, Texas. Only one grain of Anacolosidites sp. was found in the San Miguel samples. Both Elsik (1974) and Frederiksen (1988) gave a range for Anacolosidites sp. extending into the Jackson Fm. These three taxa (Nuxpollenites, Nudopollis terminalis, and Anacolosidites) are not present in the Late Claiborne Yegua Fm. sample from Brazos County diagrammed in Text-Figure 20. Only 22 taxa were recovered from this thin lignite seam; all of these are present in from the San Miguel samples. N. terminalis was present in most but not all of the levels at the Miller Clay Pit, and it is easy to believe that this palynomorph might not be present due to chance in the two Yegua coal samples mentioned in the last paragraph. It is more difficult to attribute the absence of N. terminalis from the more than 30,000 grains counted at San Miguel to chance. Because N. terminalis is more common in the lignites

than the shales of the Miller Clay Pit, it is likely that the Nudopollis plant actually lived in the Miller Clay Pit swamp. If the San Miguel were of Late Claibornian age, the total absence of Nudopollis plant in the San Miguel wetland could be ascribed to environmental differences or to regional distribution patterns, but not to chance. On the other hand, N. terminalis rarely occurs in Jackson Group rocks (Elsik, 1974), and is not present in the Lake Sommerville lignites. An assignment of the San Miguel to the Jackson Group allows a more simple explanation for the absence of N. terminalis from all the San Miguel samples.

The overall palynoflora in the San Miguel lignites is very similar to that of the Lake Somerville lignites, more so than to the Miller Clay Pit lignites. An important taxon present in the San Miguel lignites and at Lake Somerville, but not described from the Miller Clay Pit, is Caprifoliipites tantulus, previously used to place the San Miguel deposits in the Late Claiborne-Jackson interval. C. tantulus percentages average about 10% at Lake Somerville, but rise as high as 33%. C. tantulus is even more important in the Gibbons Creek lignites (Jackson Group), where it is sometimes a co-dominant with Momipites.

Elsik (1986) referred to the Yegua-Jackson lignites in Atascosa and Zapata Counties, including the San Miguel deposit, as impoverished, yet only two of the identifiable taxa at Lake Somerville, Bombacacidites nacimientos and Intratriporopollenites stavensis, are missing from the San Miguel lignite flora. These two taxa are rare, and each occurs in only one Lake Somerville lignite sample. Both of these palynomorphs range downward from the Jackson into the Upper

Claiborne. Aside from chance, the two taxa could have been excluded from the San Miguel because of environmental or sedimentological differences. The San Miguel lignite may be a much more aerially extensive deposit than Lake Somerville and less prone to edge effects.

Few palynomorph taxa are restricted to the Jackson Group, and few of these restricted taxa are present in the San Miguel samples. Unfortunately, to quote Elsik (1978), "Jackson strata are ...identifiable on negative palynologic evidence." One grain of Symplocos tecta occurs in the San Miguel lignites; according to Frederiksen (1988), the first occurrence of this species is at the base of the Jackson. Secondly, Frederiksen (1980a) reported Verrucosisporites tenuicrassus only from the Moody's Branch and Yazoo Formations (Jackson Group). Because these are relatively rare taxa their ranges may be extended later into the Late Claiborne. Taken as a whole, however, these two indicator taxa suggest a Jacksonian age for the San Miguel.

## Conclusion

Berry (1924) reported that the macroflora from the Claiborne Cockfield (=Yegua) Fm. was very similar to that of the Jackson Group. Frederiksen's (1981) conclusion, after examining palynomorph data from Mississippi and Alabama, was that the floral break between the Claiborne and Jackson Groups is "minor." (p. 20) At the present time, no reliable indicator seems to exist for defining a sample as "Yegua" or "Jackson." It is consequently simple to indicate the stratigraphic position of the San Miguel lignites as "Yegua-Jackson,"

but difficult to assign them to either unit on the basis of palynology. However, it is more probable that the San Miguel lignites belong to the Jackson Group than to the Claiborne Group. Spectra from some levels of the San Miguel lignites are very similar to spectra from some levels of the Lake Somerville lignites, and are on the whole dissimilar to those from the Late Claibornian Miller Clay Pit.

The similarity of the San Miguel palynoflora to that of the Late Claibornian Brazos County lignite sample is problematic. This sample can be easily distinguished palynologically from the Jacksonian Gibbons Creek sequence, but not from the hypothetically Jacksonian San Miguel lignites. Additionally, all available palynomorph spectra from both Jacksonian and Claibornian lignites come from locations within a fluvial or deltaic system. No spectra are available for comparison from the marginal marine environment which Gowan (1985) suggested for the San Miguel lignite deposit. The solution to these problems requires an expansion of the data base.

A quantitative examination of Eocene lignite samples of relatively certain age and from a wider variety of environmental conditions is necessary before a definite age can be assigned to the "Yegua-Jackson" beds.

# DESCRIPTION OF PALYNOMORPH SEQUENCES

Two types of palynomorph diagrams were constructed from the San Miguel data. A set of abbreviated diagrams (Plate 1) show the fifteen most important taxa. Plates 2-4 contain longer diagrams which show all of the taxa. A complete diagram of the Lake Somerville taxa is shown in Plate 4.

## C Seam

The C seam can be divided into an upper and lower section based on palynomorph content. In general, a combination of Nyssa, Rhoipites angustus, and Momipites coryloides predominate in the lower part of the seam. Small tricolpates, especially Cupuliferoipollenites, dominate the upper section. Sequence A does not exhibit this pattern; if anything, the zones are reversed. A comparison of these sequences is shown in Table 3.

**Sequence A.** Cupuliferoidaepollenites is the most important pollen type (40%) at the base of sequence A (80 cm/sample 470). Nyssa and Rhoipites angustus are present in small quantities at this level. Quercoidites inamoense levels subsequently peak with 10% at 70 cm (sample 460). From the 70 cm (sample 460) to the 10 cm (sample 400) level, Cupuliferoipollenites is the most common taxon, with a peak percentage of 60% at 50 cm (sample 440).

At 20 cm (sample 410), Cupuliferoidaepollenites liblarensis percentages again show a small peak of 10% and Sabal values spike to 9%. At the 10 cm (sample 400)

Table 3. Dominant taxa in the C Seam.

| Sequence | Dominant Type: Top Section | Bottom Section |
|---|---|---|
| A | Momipites coryloides<br>Rhoipites angustus | Cupuliferoidaepollenites<br>Cupuliferoipollenites |
| B | Cupuliferoipollenites | Rhoipites angustus,<br>Nyssa (at base),<br>Momipites coryloides |
| C | Cupuliferoipollenites | Rhoipites angustus |
| D | Cupuliferoipollenites | Momipites coryloides<br>Spores |
| E | Cupuliferoipollenites,<br>Araliaceoipolleniates<br>at base with Siltaria | Rhoipites angustus,<br>Nyssa<br>slightly more Momipites coryloides |
| F | Cupuliferoipollenites<br>with Siltaria,<br>Araliaceoipollenites granulatus | Momipites coryloides,<br>Rhoipites angustus |
| G | Cupuliferoipollenites<br>Siltaria at top | Momipites coryloides,<br>Rhoipites angustus<br>(gradual decrease)<br>Nyssa |
| H | Cupuliferoipollenites<br>Siltaria at top | Momipites coryloides at base, then<br>Rhoipites angustus<br>small amount Nyssa |

level. Momipites percentages begin to rise a peak, culminating at 45% at the top of the seam. Nyssa and Rhoipites angustus percentages are highest at the 10 cm level (7% and 19% respectively). Liliacidites percentages increase to 12% in the top sample.

Spores are important only in the uppermost levels of the seam, appearing at 30 cm (sample 420) and decreasing towards the top. The 40 cm (sample 430) level contained too few palynomorphs for interpretation.

**Sequence B.** Nyssa percentages are over 40% at the base of the C seam, but Rhoipites angustus becomes the more important taxon upwards, with 32% at 180 cm. Arecipites and Liliacidites vittatus percentages are highest in the 190 cm. sample. Momipities coryloides percentages are also relatively high (to 14%) for this core at the 170 cm. level.

Cupuliferoipollenites levels rise to 81% at 270 cm. This high level is maintained upwards to the top of the seam, with other types remaining relatively insignificant.

Spores are very rare in this sequence. The samples at 150 and 180 cm. contained too few palynomorphs for interpretation.

**Sequence C.** Rhoipites angustus percentages increase upwards to the middle of the seam, from 22% to 40%. Nyssa percentages are slightly higher (to 9%) in the lower section. Momipites coryloides percentages are not appreciably higher in the lower portion than in the top, but Cupuliferoipollenites percentages are lower at the seam base than in the upper part of the seam. Arecipites percentages are low (to 3%) but the taxon is more consistently present in the basal portion. Quercoidites inamoense percentages are slightly higher near the base of the C seam (to 8%), compared to the upper part of the C seam and to the D seam.

Rhoipites angustus percentages decrease abruptly to 9% at 30 cm. (sample 260) and Cupuliferoipollenites percentages become increasingly larger, from 39% at 30 cm. (sample 260) to 64% at 0 cm. (sample 230) Momipites coryloides values drop only at the top of the core (0cm./sample 230), where M. coryloides makes up only 2% of the total pollen, and is replaced largely by Cupuliferoipollenites.

Spores are rare in the C seam. The sample at the 10 cm. (sample 240) level had insufficient pollen for interpretation.

**Sequence D.** Nyssa and Rhoipites angustus, common at the base of most of the other C seams, are not appreciably higher at the base of the C seam and never exceed 5% in Sequence D. Momipites coryloides percentages are high in the lower 5 samples, with values ranging from 15 to 29%. Arecipites percentages are relatively high (to 10%) in samples 100 and 80, and Lilacidites exhibits a sharp peak of 19% at 70 cm. There are significant (to 12%) percentages of spores in this lower portion, with Cicatricosisporites increasing towards the middle of the section. Cupuliferoipollenites is not as common as in the upper levels of the sequence, with percentages ranging from 8 to 27% in these samples.

In the samples at 60 cm and above, Cupuliferoipollenites predominates, with values between 50 and 74%. No other pollen taxa, including Araliaceoipollenites granulatus and Siltaria, are particularly important in the upper section of the sequence. There are two peaks of Laevigatosporites, one (29%) at 60 cm in the middle of the sequence, and one (26%) at 30 cm in the middle of the portion dominated by Cupuliferoipollenites.

One level, 40 cm, near the top of the seam, contained insufficient pollen for interpretation.

**Sequence E.** Araliaceoipollenites granulatus is the most important pollen grain (29%) at the base of the C seam. Rhoipites angustus makes up 9% of the spectrum at this level and percentages rise to 34% in the next higher sample. The R. angustus percentage returns to 10% at 270 cm. Nyssa percentages are also relatively high at 280 cm. Momipites coryloides attains moderate levels in the lower samples.

The percentage of "degraded small tricolporates" rises to almost 50% at 270 cm. Above this level, Cupuliferoipollenites is the dominant taxon. Near the top of the seam, Cupuliferoidaepollenites and Siltaria become more important, and Momipites coryloides percentages decrease.

Spores are insignificant in this seam. The 260 cm sample, above the level with so many "degraded tricolporates," contained too few palynomorphs for interpretation.

**Sequence F.** Momipites coryloides, with values to 34%, and Rhoipites angustus, with values to 13%, occur commonly in the lower portion of this sequence. These higher values continue into the middle of the seam, although Cupuliferoipollenites is relatively abundant in this portion (to 36%) and Araliaceoipollenites granulatus values begin to rise (to 8%) along with Cupuliferoipollenites.

Two of the samples (10 cm and 20 cm) in the upper portion of the seam contain insufficient pollen for interpretation; only the uppermost sample (0 cm) is available for analysis. Cupuliferoipollenites is most abundant (41%) in the uppermost sample. The other small tricolporates, Siltaria and Araliaceoipollenites

granulatus, Momipites coryloides and Rhoipites angustus have very low percentages (<5%) at the top of the seam.

Spores are insignificant in the C seam.

**Sequence G.** Quercoidites microhenricii is an important (18%) taxon at the base of the C seam (100 cm). Momipites coryloides (27%) and Rhoipites angustus (21%) are significant taxa at the next higher (90 cm) level, but rapidly decline toward the middle of the seam. Nyssa is present only in the lower portion of the seam. Q. inamoense is more abundant in the lower part of the seam.

Cupuliferoipollenites is the dominant taxon (to 59%) at 80 cm and higher levels. Siltaria also becomes important at this level, but percentages are highest at the top of the core (0-10 cm), where Siltaria levels reach 23%. Araliaceoipollenites granulatus percentages are in general low, but rise slightly at the top of the seam. Quercoidites microhenricii percentages rise again at 0 and 10 cm. (to 17%). Cupuliferoipollenites peaks in the middle of the seam (40 to 60 cm) and decreases towards the top (26% at 0 cm).

Spores are not important in this seam, and are present only at the two lowermost levels. Two of the upper samples, at 20 and 30 cm, contained too few pollen grains for interpretation.

**Sequence H.** Momipites coryloides is the most important pollen type (35%) at the seam base. The percentages are relatively low (<10%) throughout the rest of the seam. At 10 cm, Rhoipites angustus percentages rise to 38% and are greater than 10% in the next two levels. Cupuliferoipollenites becomes most important (56%) at 20 cm; percentages then fall to less than 50% going upwards in the seam. Siltaria is most important at the 40 cm level. The samples above this

contained too few grains for interpretation. Spores are not important in sequence H.

D Seam

In the D seam, Momipites coryloides and Cupuliferoipollenites alternate in abundance. Prominent peaks of palms (Arecipites and Liliacidites) and spores (Cicatricosisporites and Laevigatosporites) also occur in most of the sequences. Table 4 shows the sequence of dominant palynomorphs in the D Seam of these cores.

**Sequence B.** Cupuliferoipollenites-Chrysophyllum is the most important (34%) taxon at the base of the D seam, with Cupuliferoidaepollenites (23%) and Momipites coryloides (22%) percentages also relatively high. Above this level, Cupuliferoipollenites rises, peaking at 87% at 310 cm. Above this, there is a slight peak of Rhoipites angustus at 280 cm, and a slow rise in Cupuliferoidaepollenites to a spike of 81% at 260 cm. Cupuliferoipollenites becomes again more common above this level.

Three peaks of Momipites coryloides occur in sequence B: at the base of the seam (340 cm), in the middle of the seam (290 cm), and at the top of the seam (240 cm). These peaks coincide with intermediate levels of both Cupuliferoidaepollenites and Cupuliferoipollenites, and, to some extent, with higher levels of Rhoipites angustus.

Spores are rare in this sequence.

**Sequence C.** Laevigatosporites (24%) dominates the base of the D seam. Quantities of Momipites coryloides and Cupuliferoipollenites are approximately equivalent

Table 4. Dominant taxa in the D Seam.

Sequence B

(Top)
Momipites coryloides, Rhoipites angustus
Cupuliferoipollenites, Nyssa
Cupuliferoidaepollenites
Arecipites, Momipites coryloides, Rhoipites angustus
Liliacidites, Cyrillaceaepollenites
Cupuliferoipollenites
Arecipites
Momipites coryloides, Cupuliferoidaepollenites
(base may be missing)

Sequence C

(Top)
Cupuliferoipollenites
Siltaria, Arecipites
Rhoipites angustus, Nyssa
Cupuliferoipollenites
Laevigatosporites, Momipites coryloides
Quercoidites microhenricii
Laevigatosporites

Sequence E

(Top)
Cupuliferoipollenites, Rhoipites angustus
Cupuliferoidaepollenites, Arecipites, Siltaria
Cupuliferoipollenites
Momipites coryloides, Arecipites, "degraded small tricolporates," Nyssa
Laevigatosporites, Cicatricosisporites
Momipites coryloides
Cupuliferoidaepollenites, Cupuliferoipollenites, Siltaria, Araliaceaepollenites granulatus

Table 4. Continued

Sequence F

(Top)
(Missing)
Laevigatosporites, Cupuliferoipollenites
Cupuliferoipollenites, Siltaria, Araliaceoipollenites,
Nyssa, Rhoipites angustus
Momipites coryloides
Laevigatosporites (minor), Liliacidites,
Araliaceoipollenites, Siltaria
Cupuliferoipollenites
Momipites coryloides, Rhoipites angustus, Nyssa
Cupuliferoipollenites, Rhoipites angustus, Nyssa

Sequence G

(Top)
Cupuliferoipollenites, Rhoipites angustus, Nyssa
Momipites coryloides
Laevigatosporites, Cictricosisporites, Siltaria
Araliaceoipollenites
Momipites coryloides, Rhoipites angustus
Quercoidites microhenricii, Cupuliferoipollenites,
Siltaria, Araliaceoipollenites

(14-16%); very little Nyssa and no Rhoipites angustus occurs in this sequence. Quercoidites microhenricii spikes to 57% just above the base. Percentages for Momipites coryloides are consistently highest (to 15%), but not dominant, in the lower middle section of the seam. One peak (11%) of Rhoipites angustus at 70 cm (sample 410) coincides with the Momipites peak, but another (16%) at 40 cm. (sample 320) does not. R. angustus is abundant along with Nyssa only in the middle of the seam.

Cupuliferoipollenites values become very large (67%) at 50 cm. (sample 390) and remain so upwards in the seam. The Cupuliferoipollenites percentage is somewhat lower at 20 cm. (sample 300), where Siltaria values rise to 29%.

Both Laevigatosporites and Cicatricosisporites are important, notably at the base of the seam. Values gradually decrease to the middle of the core, but another very minor peak of Laevigatosporites occurs at 20-30 cm. (samples 300 and 310) A small peak of Arecipites and Liliacidites vittautus coincides with the upper spore peak.

**Sequence E.** All three small tricolporates, Cupuliferoipollenites, Siltaria, and Araliaceoipollenites granulatus, are common at the base of the seam, with a total percentage of over 65%. Cupuliferoidaepollenites is present at 15%. The percentages fall upwards in the core, and Momipites coryloides peaks at 440 cm. (31%) and 400 cm (24%). "Degraded small tricolporates" become important at 410 cm, and Cupuliferoipollenites again peaks at 390 cm. (70%). The rise coincides with a fall in M. coryloides to less than 5% which is continued to the top of the seam. Siltaria reaches percentages of over 30% near the

top of the seam, at 360 and 370 cm. Rhoipites angustus and Nyssa are present at levels less than 10% throughout the seam. R. angustus rises towards the top of the seam, and Nyssa exhibits a slight peak at 410 cm.

There is a significant peak of Laevigatosporites and Cicatricosisporites culminating at 430 cm., with combined values as high as 90%. Significant spikes of Arecipites appear at 360 and 410 cm.

**Sequence F.** At the base of the D Seam, small tricolporates are the most important palynomorphs. These types alternate with a combination of Momipites coryloides and Rhoipites angustus as dominants. There are two Momipites/Rhoipites peaks, at 70 and 110 cm. Nyssa is usually but not always associated with the higher R. angustus values, and the three tricolpates do not always follow the same pattern. There is a large (18%) Liliacidites spike at 80 cm which coincides with a slight peak in Laevigatosporites. A major Laevigatosporites spike (47%) appears at 40 cm., co-occurring with a high (44%) Cupuliferoipollenites value.

**Sequence G.** The three tricolporates, Cupuliferoipollenites, Siltaria, and Araliaceoipollenites granulatus share dominance at the base of the D seam. There are two Momipites coryloides peaks, one at 60 cm and one at 100 cm. A relatively high (8%) percentage of Rhoipites angustus occurs at 100 cm., but R. angustus is absent from the 60 cm level. Cupuliferoipollenites percentages are uniformly high in the upper 60 cm of the seam, rising to 71% in the uppermost sample. R. angustus and Nyssa values are relatively high (to 7 and 16%) in the three upper levels of the core where Cupuliferoipollenites percentages are highest.

Significant numbers of spores are present between 60 and 100 cm, with a spike (28%) of Cicatricosisporites at 70 cm. The spike coincides with a low in Momipites coryloides. Arecipites is more common at these levels, but Liliacidites vittatus is most abundant near the top of the seam.

Other Seams

**Sequence B, A Seam.** Only two samples are available, from the base of the A Seam. Cupuliferoipollenites-Chrysophyllum make up 80% of the total pollen in one sample, with Momipites coryloides only 6% of the palynomorph sum. The M. coryloides percentage is slightly higher in the other sample.

**Sequence E, A Seam.** Two samples are available from this sequence. Cupuliferoipollenites is most common (52%) at the base. The highest values of Siltaria (6%) and Rhoipites angustus (6%) are also at the base. Momipites coryloides percentages rise from 9% at the base to 26% at the top of the seam; Cupuliferoidaepollenites percentages are highest (15%) in the upper level, as is Liliacidites vittatus (4%).

**Sequence E, B Seam.** Only one sample is available from the B seam. Momipites coryloides is the most common taxon (23%), followed by Cupuliferoipollenites (17%).

**Sequence E, E Seam.** The spectrum from the E seam of Sequence E is dominated by Arecipites (39%) and Momipites coryloides (32%). No other pollen types are present in quantities of over 5%. Laevigatosporites is present at 6%.

**Sequence F, E Seam.** The spectrum from the E seam of Sequence F is dominated by Momipites coryloides (40%) and Rhoipites angustus (26%).

The Overburden

**Sequence B, Overburden.** The two overburden spectra from the B sequence are from just above the A seam. Both spectra are similar. Cupuliferoipollenites is the most common grain, with percentages of 37% and 47%. Also common are Cupuliferoidaepollenites (22% and 23%) and Momipites coryloides (9 and 16%). Liliacidites vittatus is slightly more common, although only to 5%, than in most of the lignite. Arecipites, Siltaria, Araliaceoipollenites granulatus, Nyssa, and Rhoipites angustus are consistently present.

**Sequence E, Overburden.** In general, Momipites coryloides is the most common taxon (20%-35%) in the overburden of sequence E. Cupuliferoidaepollenites and Cupuliferoipollenites are also common, and Liliacidites vittatus is more common here than in the rest of the sequence. Arecipites, Quercoidites inamoense, Siltaria, and Rhoipites angustus are consistently present.

Partings

**Sequence B, A/B Parting.** Momipites coryloides is the most important taxon (35%) at the base of the B/C parting, followed by Cupuliferoidaepollenites (27%), Cupuliferoipollenites-Chrysophyllum (7%), and Rhoipites angustus (5%).

**Sequence B, B/C Parting.** Cupuliferoipollenites is the dominant grain (62%). Siltaria percentages are at 10%, Momipites coryloides at 7%, and Rhoipites angustus at 5%.

**Sequence E, B/C Parting.** The basal sample contained too few palynomorphs for interpretation. Cupuliferoipollenites is the most important (37%) palynomorph at the lowest sample, systematically decreasing to 17% at the top. Araliaceoipollenites granulatus is also more abundant (19%) at the base. Cupuliferoidaepollenites, Quercoidites microhenricii, and Siltaria are most common in the middle of the parting. Momipites coryloides values, at 4% near the base, systematically increase to 23%.

**Sequence B, C/D Parting.** The C/D parting is dominated by Cupuliferoipollenites-Chrysophyllum, with percentages to 90% in the middle of the parting. Cupuliferoidaepollenites is important at both bottom (25%) and top (15%) levels.

**Sequence E, D/E Parting.** Only the lower level is available for this parting. The value for Cupuliferoipollenites is 2%, Momipites coryloides, 30% and Arecipites, 34%.

Lake Somerville

Momipites coryloides is the dominant palynomorph in most of the samples from the Lake Somerville Spillway. Table 5 gives a synopsis of taxon peaks in the Somerville seams.

**Lower Seam.** Liliacidites vittatus percentages are fairly high (15%) at the base of the Lower Seam; Peaks of Rhoipites angustus (23%) and Nyssa (15%) occur above

Table 5. Dominant taxa at Lake Somerville.

Upper Seam (Top):
Cupuliferoipollenites, Cyrillaceaepollenites ventosus
Momipites, Chrysophyllum brevisulcatum,
Cyrillaceaepollenites
Momipites, Liliacidites vittatus, Arecipites
Momipites, Rhoipites angustus
Momipites, Liliacidites vittatus, Arecipites
Laevigatosporites, Cicatricosisporites

Lower Seam (Top):
Cupuliferoidaepollenites, Cupuliferoipollenites
Momipites, Cyrillaceaepollenites, Siltaria, Nyssa,
Rhoipites angustus
Momipites, Liliacidites vittatus, Arecipites,
Monocolpopollenites, Horniella, Caprifoliipites tantulus
Momipites, Nyssa, Rhoipites angustus
Momipites, Liliacidites vittatus, Intratriporopollenites
stavensis

the base followed by a peaks of the palms Liliacidites, Monocolpites, and Arecipites. Cupuliferoipollenites increases in the upper half of the seam. Small peaks of Nyssa and R. angustus, larger peaks of Horniella and Siltaria, and a 35% peak in Caprifoliipites tantulus also occur here. From this level upwards, Cupuliferoidaepollenites and Cyrillaceae increase steadily, and at the top, Cupuliferoipollenites dominates (47%). Ilex occurs only in the upper part of the seam.

**Clastic Sample.** Momipites coryloides composes 29% and Cupuliferoidaepollenites 18% of the sample. Microfoveolatosporites is unusually common at 6%.

**Upper Seam.** The base of the upper seam is dominated by the spores Cicatricosiporites (59%) and Laevigatosporites (32%). Cicatricosisporites is almost absent in the rest of the seam, but Laevigatosporites decreases gradually upwards. A peak of Caprifoliipites tantulus occurs above the spore layer, as well as a Liliacidites peak and a small peak of Arecipites; these are both palms. Rhoipites angustus peaks in the middle of the seam; Nyssa occurs only in the lower and middle sections and only in small quantities. Above the R. angustus peak is another Liliacidites and Arecipites peak, and a relatively high percentage (21%) of Chrysophyllum. A small peak of C. tantulus occurs just above this. At the top of the seam, Cupuliferoipollenites (63%) dominates. Cyrillaceaepollenites also peaks at the top level.

# STATISTICAL ANALYSIS

## Multivariate Analysis: Cluster Analysis

**Introduction.** Cluster analysis arranges groups into a hierarchical, branching structure called a dendrogram. There are two steps in cluster analysis. First, a similarity matrix is calculated using one of numerous formulas. Then the clustering procedure is applied successively to build up a hierarchy of increasingly large clusters. (Gauch, 1982)

**Analysis and Results.** I performed cluster analyses on data from the C Seam of each San Miguel lignite sequence, using the CLUST program written by J.J. Sepkoski, Jr. and J. Sharry, and formatted for personal computer by W. C. Parker. Only taxa present at 1.5% (rounded to 2%) or more in at least one level were included in the analyses. This cut-off point was chosen empirically; more taxa created results that were more difficult to interpret. According to Gauch (1982), "Rare species are usually deleted from a data matrix prior to multivariate analysis...The occurrence of rare species is usually more a matter of chance than an indication of ecological conditions (p. 213-214)."

To utilize cluster analysis, data were first converted into similarity matrices for both taxa and samples. I used the [Pearson product moment] correlation coefficient option included in the SIMIL program, also written by Sepkoski and Sharry and formatted for the P.C. by W.C. Parker. This method uses a relatively complicated formula to determine the similarity matrix:

$$PCC_{ij} = \frac{\sum_k (X_{ik} - \overline{X_i})(X_{jk} - \overline{X_j})}{\left(\sqrt{\left(\sum_k (X_{ik} - \overline{X_i})^2\right)}\right)\left(\sqrt{\left(\sum_k (X_{jk} - \overline{X_j})^2\right)}\right)}$$

where i and j represent two columns of the data matrix, k represents the rows, and $X_{ik}$ represent the datum in the kth row of the ith column (Kovach, 1989).

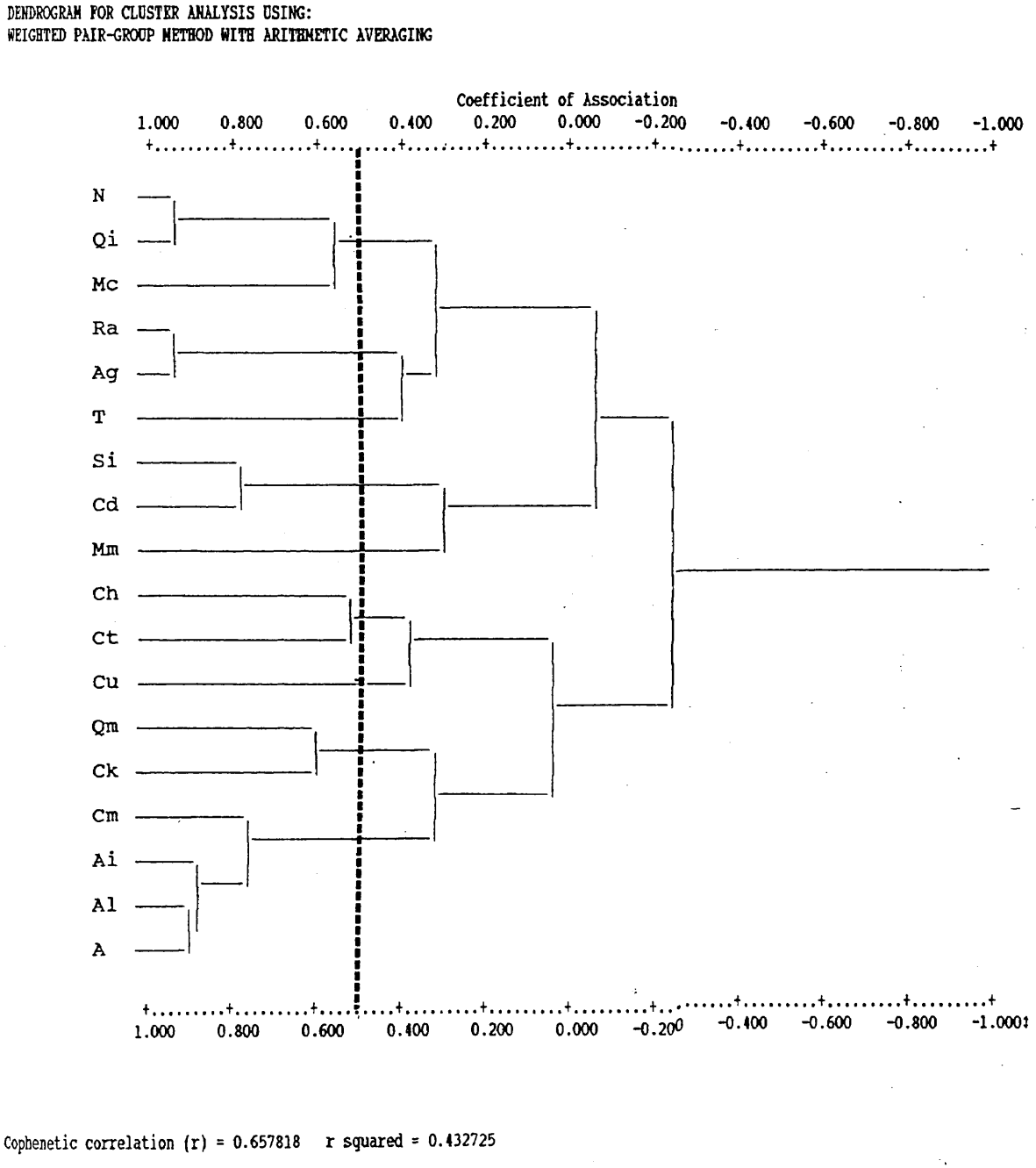
Boulter and Hubbard (1982) used the Pearson Product method to determine similarity matrices for cluster analysis in conjunction with a paleoecological study of Eocene palynomorphs from Britain's Hampshire Basin. They explained that their results were successfully interpreted because the Pearson Product similarity matrix is based on the rank order of taxon abundance rather than on the number of specimens. The method allows the cluster dendrogram to display commonalities based on the mutuality of variation rather than the amplitude of variation. Because rank order and not raw data is used to create the matrix, no transformations are necessary. Kovach (1989) used an environmentally defined Cretaceous palynomorph sequence to compare cluster diagrams generated using a variety of similarity techniques. He found rank order methods to be superior for clustering palynological data because they minimize random variation.

I ran the CLUST program using all three available options; these included weighted and unweighted pair groups with arithmetic averaging, and complete linkage. The results from the three methods were similar, with only one or two taxa clustered in different areas of the dendrograms. Only the results of the arbitrarily chosen weighted pair group arithmetic averaging option are presented here. As an example, the cluster diagram from

Sequence C is shown in Text-Figure 21; abbreviations are given in Table 6. The remaining cluster diagrams are given in Appendix 2.

In order to discern whether taxon clusters in all seven analyses were repeated in the different palynomorph sequences, I constructed a line at the +0.5 coefficient of association level in the cluster diagram printouts; this division yielded easily compared units of one to six taxa. These resulting clusters are shown in Table 7. The most obvious common cluster includes Momipites coryloides, Nyssa, and Rhoipites angustus. These three taxa are linked above the 0.5 level in Sequence H. In sequences B, C, F, and G, M. coryloides (Momipites sp. in sequence B) clusters with either Nyssa or R. angustus above the 0.5 level, and, in the next closest cluster, with the remaining of the three taxa at a lower coefficient of association. In Sequence E, M. corlyloides links with the other two taxa in the next higher cluster. R. angustus and Nyssa cluster together above the 0.5 level in sequence A, but are negatively correlated with M. coryloides. The coefficient of association between these three taxa is zero or negative in sequence D.

Cupuliferoipollenites is not linked at the +0.5 level with any other taxon in sequences B, C, D, G, and H. In sequence A, it is linked with another small tricolporate, Siltaria, and with Cupaneidites, a relatively rare taxon. In sequence E, it is linked with Momipites microfoveolatus. In sequence F, it is linked with seven taxa, including Siltaria, and M. microfoveolatus. Cupuliferoipollenites has a negative association with Momipites coryloides in all of the sequences.




Text-Figure 21. Dendrogram for pearson product cluster analysis, Sequence C (C Seam) taxa. Abbreviations are given in Table 6.

Table 6. Abbreviations used in reciprocal averaging plots.

Taxa

A *Arecipites columellus*
Ag *Araliaceoipollenites granulatus*
Ai *Ailanthipites*
Al *Alangiopollis*
Ap *Arailiaceoipollenites profundus*
Cd *Cupuliferoidaepollenites*
Ch *Chrysophyllum*
Ci *Cicatricosisporites*
Ck *Cyrillaceaepollenites kedvesii*
Cm *Cyrillaceaepollenites megaexactus*
Cp *Cupanieidites orthoteichus*
Ca *Caprifoliipites tantulus*
Cu *Cupuliferoipollenites*
Cv *Cyrillaceaepollenites ventosus*
Cy *Cyrillaceaepollenites* sp.
F *Foveotricolporites*
Fs *Fraxinoipollenites* (Small)
Hs *Horniella* (Small)
Hl *Horniella* (Large)
I *Ilex* spp.
La *Laevigatosporites*
Li *Liliacidites vittatus*
Lt *Liliacidites tritus*
Ly *Lygodiumsporites adriennis*
Mc *Momipites coryloides*
Mm *Momipites microfoveolatus*
Mo *Monocolpopollenites*
N *Nyssa*
P *Polypodiisporonites*
Qi *Quercoidites inamoense*

Table 6. Continued.

Qm Quercoidites microhenricii
Ra Rhoipites angustus
Rl Rhoipites latus
Sa Sabal
Si Siltaria
T Tetracolporopollenites
Vt Verrutricolporites cruciatus

Table 6. Continued.

Samples

San Miguel

| Sequence A | Sequence C | Sequence D |
|---|---|---|
| A1 390c | C1 230c | D1 10c |
| A2 400c | C2 250c | D2 20c |
| A3 410c | C3 260c | D3 30c |
| A4 420c | C4 330c | D4 40c |
| A5 440c | C5 340c | D5 50c |
| A6 450c | C6 350c | D6 60c |
| A7 460c | C7 360c | D7 80c |
| A8 470c | | D8 90c |
| | | D9 100c |
| | | D10 110c |

| Sequence E | Sequence F | Sequence G | Sequence H |
|---|---|---|---|
| E1 210c | F1 0c | G1 0c | H1 40c |
| E2 230c | F2 30c | G2 10c | H2 30c |
| E3 240c | F3 40c | G3 40c | H3 20c |
| E4 250c | F4 50c | G4 50c | H4 10c |
| E5 260c | F5 60c | G5 60c | H5 0c |
| E6 270c | | G6 70c | |
| E7 280c | | G7 80c | |
| E8 290c | | G8 90c | |
| | | G9 100c | |

Table 6. Continued.

Lake Somerville

| Lower Seam | O "Overburden | Upper Seam |
|---|---|---|
| 01 0 | | 1u 10 |
| 11 10 | | 2u 20 |
| 21 20 | | 3u 30 |
| 31 30 | | 4u 40 |
| 41 40 | | 5u 50 |
| 51 50 | | 6u 60 |
| 61 60 | | 7u 70 |
| 71 70 | | 8u 80 |
| 81 80 | | 10u 100 |
| 91 90 | | |

Highwall Sequences

| | | | |
|---|---|---|---|
| M1 Mini 10 | S1 Seambase 1 | A1 Ash 1 | H0 Sequence H 0 |
| M2 Mini 20 | S2 Seambase 2 | A3 Ash 3 | H1 Sequence H 10 |
| M3 Mini 30 | S3 Seambase 3 | A4 Ash 4 | H2 Sequence H 20 |
| M4 Mini 40 | S4 Seambase 4 | A5 Ash 5 | H3 Sequence H 30 |
| M5 Mini 50 | S6 Seambase 6 | A6 Ash 6 | H4 Sequence H 40 |
| M6 Mini 60 | S8 Seambase 8 | | |
| M7 Mini 70 | S10 Seambase 10 | | |
| M9 Mini 90 | | | |
| M10 Mini 100 | | | |

Table 7. Clusters at the .5 level of association in the San Miguel sequences. Taxon groups are numbered from the top of the cluster dendrograms.

Sequence A; $r^2$=.65

1. Sabal, Cicatricosisporites, Laevigatosporites
2. Liliacidites, Momipites coryloides, Arecipites
3. Cyrillaceaepollenites megaexactus, C. kedvessii, Chrysophyllum, Quercoidites inamoense, Monocolpopollenites
4. Cupaniedites, Siltaria, Cupuliferoipollenites
5. Araliaceoipollenites granulatus
6. Araliaceoipollenites profundus, Nyssa, Rhoipites latus, R. angustus, Foveotricolpites
7. Quercoidites microhenricii, small Fraxinoipollenites, Cupuliferoidaepollenites, Liliacidites tritus, Momipites microfoveolatus

Sequence B; $r^2$=.73

1. Rhoipites angustus, Momipites sp.
2. Nyssa, Cyrillaceaepollenites sp.
3. Cupuliferoipollenites
4. Cupuliferoidaepollenites
5. Caprifoliipites, small Horniella, Siltaria, Arecipites

Table 7. Continued.

Sequence C; $r^2$=.43

1. Nyssa, Quercoidites inamoense, Momipites coryloides
2. Rhoipites angustus, Araliaceoipollenites granulatus
3. Tetracolporopollenites
4. Siltaria, Cupuliferoidaepollenites
5. Momipites microfoveolatus
6. Chrysophyllum, Caprifoliipites tantulus
7. Cupuliferoipollenites
8. Quercoidites microhenricii, Cyrillaceaepollenites kedvessii
9. Cyrillaceaepollenites megaexactus, Ailanthipites, Alangiopollis, Arecipites

Sequence D; $r^2$=.47

1. Ailanthipites, Liliacidites, Laevigatosporites
2. Arecipites
3. Lygodiumsporites adriennis
4. Momipites coryloides, Cicatricosisporites, Chrysophyllum, Cyrillaceapollenites kedvesii
5. Cupaneidites, Monocolpopollenites, small Fraxinoipollenites, Rhoipites latus, Cyrillaceaepollenites ventosus

Table 7. Continued.

6. Nyssa, Verrutricolporites, Momipites microfoveolatus
7. Quercoidites microhenricii, Sabal, Cyrillaceaepollenites megaexactus
8. Quercoidites inamoense, Cupuliferoidaepollenites
9. Arailiaceoipollenites granulatus, Siltaria
10. Caprifoliipites tantulus, Rhoipites angustus
11. Cupuliferoipollenites

Sequence E; $r^2$=.59

1. Arecipites, Lygodiumsporites adriennis
2. Cupuliferoipollenites, Momipites microfoveolatus
3. Siltaria, Cyrillaceapollenites sp., Tetracolporopollenites
4. large and small Horniella, Ilex media, Caprifoliipites tantulus, small Fraxinoipollenites, Cyrillaceaepollenites? ventosus, Cupuliferoidaepollenites
5. Chrysophyllum, Araliaceoipollenites granulatus, Quercoidites inamoense
6. Araliaceoipollenites sp., Rhoipites angustus, Nyssa
7. Momipites coryloides

Sequence F; $r^2$=.61

1. Rhoipites, Momipites coryloides
2. Nyssa, Quercoidites inamoense
3. small Fraxinoipollenites,
4. Quercoidites microhenricii, Cupuliferoidaepollenites Cyrillaceapollenites sp., Liliacidites, Arecipites, Sabal
5. Ailanthipites, Siltaria, Tetracolporopollenites,

Table 7. Continued.

Chrysophyllum, Araliaceoipollenites granulatus, Caprifoliipites tantulus, Cupuliferoipollenites, Momipites microfoveolatus

Sequence G; $r^2$=.39

1. small Fraxinoipollenites, Polypodiisporonites, Caprifoliipollenites tantulus
2. Cyrillaceaepollenites sp.
3. Cupuliferoipollenites
4. Tetracolporopollenites, Cupuliferoidaepollenites
5. Araliaceaepollenites granulatus
6. Chrysophyllum
7. Cyrillaceaepollenites? ventosus
8. Arecipites
9. Rhoipites angustus, Quercoidites inamoense, small Horniella, Momipites coryloides
10. Nyssa
11. Siltaria, Quercoidites microhenricii, Momipites microfoveolatus, Liliacidites, Cicatricosisporites

Sequence H; $r^2$=.53

1. Nyssa, Momipites coryloides, Rhoipites angustus, Quercoidites microhenricii, Momipites microfoveolatus
2. Cupuliferoidaepollenites, Liliacidites
3. Chrysophyllum, Araliaceoipollenites granulatus, Siltaria, Quercoidites microhenricii
4. Arecipites
5. Cupuliferoipollenites

Table 7. Continued.

Lake Somerville; $r^2$=.64

1. Laevigatosporites
2. Cyrillaceapollenites sp.
3. Chrysophyllum brevisulcatum
4. Caprifoliipites tantulus, Salixipollenites parvus
5. Cupuliferoipollenites, Cupuliferoidaepollenites
6. Rhoipites angustus, Nyssa
7. Momipites coryloides
8. Arecipites columellus
9. Rhoipites latus, Liliacidites vittatus
10. Momipites microfoveolatus, Polypodiisporonites

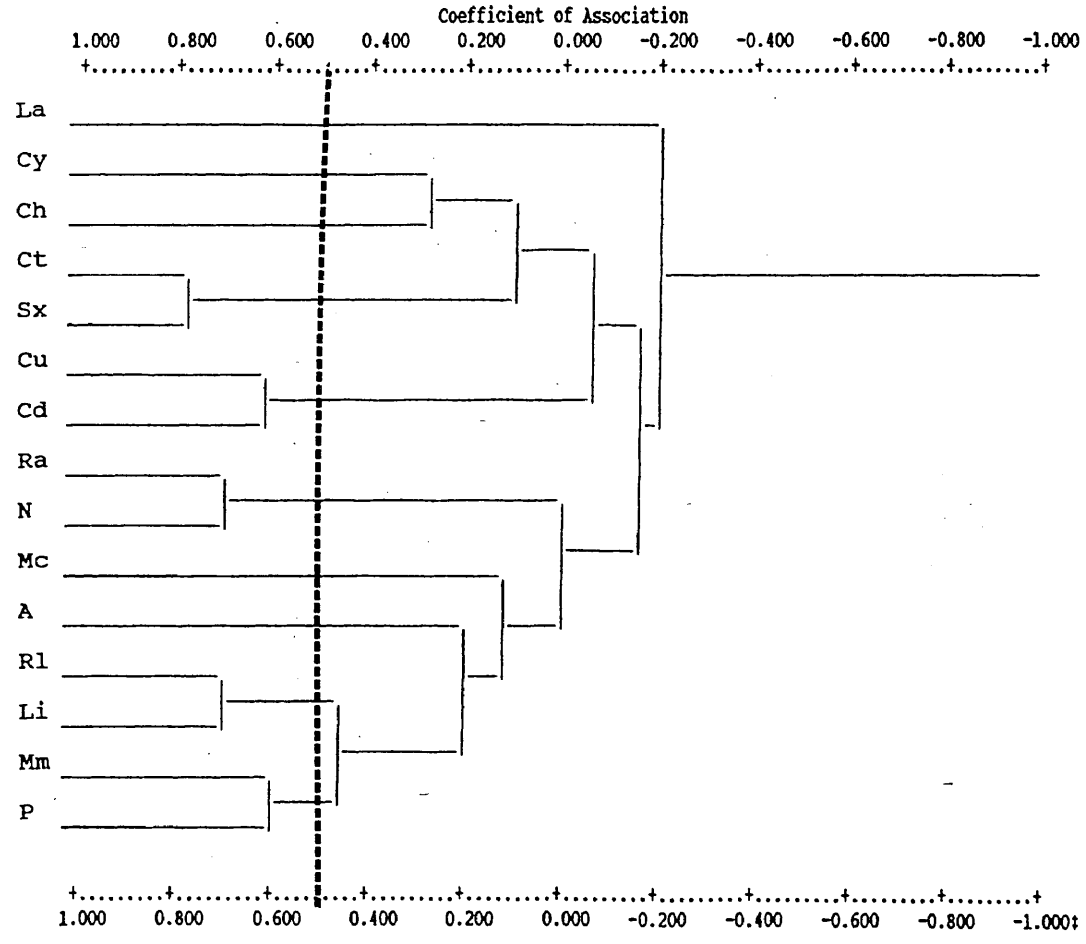
In most cases, where spores are present in adequate quantities for analysis, they are associated with monolete ("palm") pollen. The exception to this phenomenon is sequence D where, although Laevigatosporites is linked to Liliacidites, no palms or other spores are linked closely to Cicatricosisporites. "Palms" and spores are never closely linked to Cupuliferoipollenites or Nyssa, but in core D, Cicatricosisporites is linked to Momipites coryloides, and Monocolpopollenites is linked to Rhoipites angustus.

No other relationships seem to be consistently present and discernable using the clustering technique.

I also analyzed the lignite samples from Lake Somerville using the same methods. In order to decrease the larger taxon list, I included only taxa with five or more levels with over 2% (rounded). The results are shown in a cluster diagram (Text-Figure 22) and in Table 7. Nyssa and Rhoipites angustus form a cluster, but Momipites coryloides is negatively correlated with this cluster. Cupuliferoipollenites, which is linked above the 0.5 level to Cupuliferoidaepollenites, is negatively linked to both Nyssa-R. angustus and M. coryloides. The spore Laevigatosporites is negatively correlated to all other taxa, but clusters with Cicatricosisporites and Microfoveolatus when more taxa are added to the analysis. There is no link between spores and monocolpates. Polypodiisporonites is linked to Momipites microfoveolatus.

The square of the cophenetic correlation coefficient (r2) is listed for each sequence in Table 7. The r2 gives a rough estimation of the amount of variation in the similarity matrix that is reflected in the cluster diagram. An r2 of less than 0.5, which

DENDROGRAM FOR CLUSTER ANALYSIS USING:
WEIGHTED PAIR-GROUP METHOD WITH ARITHMETIC AVERAGING




Cophenetic correlation (r) = 0.800692 r squared = 0.641108

Text-Figure 22. Dendrogram for Pearson product cluster analysis, Lake Somerville taxa. Abbreviations are given in Table 6.

occurs for sequences C (.43), D (.47) and G (.39), suggests that much of the relationship between taxa does not appear in the clusters. This suggestion implies that the results of cluster analysis for these sequences reflects only a small proportion of the information present in the similarity matrix. When cluster analyses were performed using unweighted pair-group with arithmetic averaging and complete linkage techniques included in the CLUST program, the r2 was not increased.

## Multivariate Analysis: Reciprocal Averaging (Correspondence Analysis)

**Introduction.** Reciprocal averaging (RA) was developed by Hirschfield (1935) and Fisher (1940); Hill (1973; 1974) introduced the method to ecologists. RA ordinates samples and species simultaneously. Initially, species ordination scores are assigned arbitrarily. Sample scores are obtained from these species scores using weighted averages. New species scores are then produced using weighted averages of the sample scores. (Weighted averages are discussed by Gauch (1982, p. 120-126.) The process is continued until the scores stabilize. The first RA axis has the property of maximizing the correlation of samples and species, so usually one or a few RA axes are adequate. Gauch (1982) and Kovach (1989) believed RA to be superior to PCA (Principal Component Analysis) in the analysis of community data sets.

According to Gauch (1982), "Ordination primarily endeavors to represent sample and species relationships as faithfully as possible in a low-dimensional

space...The end product is a graph, usually two-dimensional, in which similar samples or species or both are near each other and dissimilar entities are far apart." He added: "The advantage of low-dimensionality is workability for contemplation and communication; the disadvantage is that some degree of fidelity to the data structure must be frequently sacrificed..." (p. 15).

Both PCA and RA are subject to an "arching problem." This means that, instead of a continuum of related species or sites being situated in a straight line on the graph, it forms an arch. In PCA, the arch may become involuted, so that entities which are at opposite ecological poles are brought into juxtaposition. This does not occur in RA. Gauch cited three additional faults of RA. The second axis may be a quadratic distortion of the first axis, which implies that a graph of the first vs. second axis may reflect only one axis. A second fault is that the first axis ends tend to be compressed, leading to the false interpretation that end members are closer to each other ecologically than they actually are. This latter fault would be more important to ecologists with data sets which represent individuals living in definite niches. Pollen and spore data sets consist of gametophytes which, like paleontological death assemblages, may be dispersed beyond the niche of the parent plant, and relative distances on a plot may be irrelevant considering the amount of ecological error inherent in the data. Thirdly, rare species are treated as extremely distinctive and are placed at the ends of axes.

Gauch added that points interior to the arch may represent broadly ranging species or samples with a wide range of taxa. Peripheral points may represent species

with narrow distributions, or samples with only a few species.

Kovach (1988), in his study of a Cenomanian megaspore flora, stated that RA is "...particularly well suited for distinguishing single, major gradients on the first axis, although they are susceptible to domination by outlying samples..." (p. 268). He found that the use of RA on his data yielded a "...clear ecological gradient along the first axis, ranging from algal cysts, which are restricted to marine deposits, to the bilobed cuticular structures, which are only found in terrestrial deposits." (p. 256)

**Analysis and Results.** RA values were computed for all sequences and for the Lake Somerville lignites using the MVSP program developed by Warren Kovach. I also computed RA values for a "composite" C seam, containing all sequences except B. B was omitted because several of the taxa were lumped for counting. All RA plots are presented in Appendix 2. As was done in the cluster analysis of Lake Somerville, in order to limit the number of taxa in the composite analysis and thereby avoid confusion, only taxa with 5 or more occurrences of 2% or greater (rounded) were included.

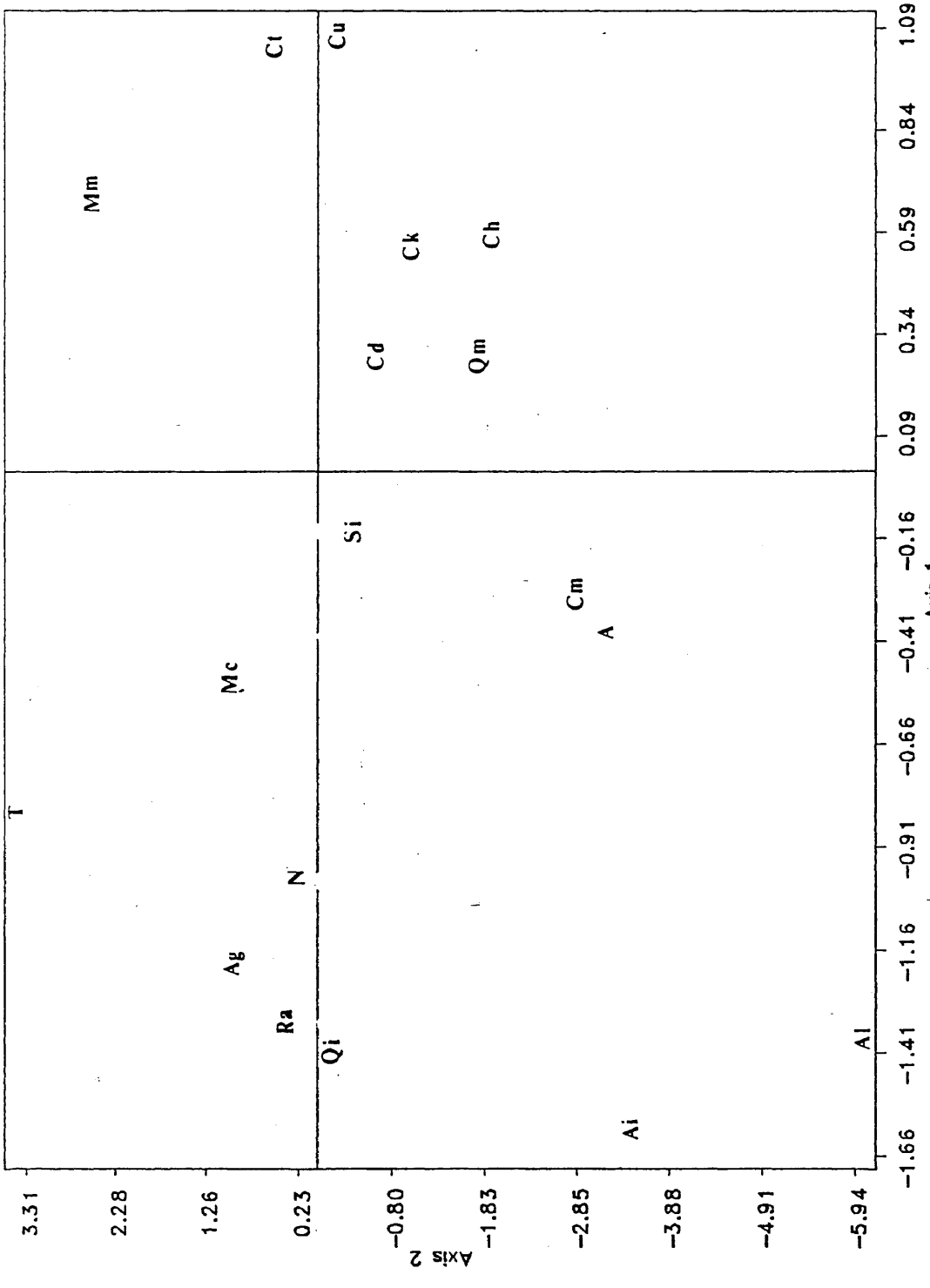
RA values were computed using raw data, transformed data, and raw data with rare species weighted. When the two latter types were plotted using the MVSP program, the most common taxa, Cupuliferoipollenites and Momipites coryloides invariably were grouped together. Consequently, only the diagrams of RA's using raw data are presented here. Plots given are of axis 1 vs. axis 2 only. Taxon names are abbreviated on the RA plots, and these abbreviations are given in Table 6.

No clear pattern emerges from the sequence diagrams; the species are scattered and do not seem to

indicate a well-defined environmental gradient. The graph for Sequence C is shown in Text-Figure 23 as an example. Table 8 describes the position of several important taxa on these graphs. In most cases, Cupuliferoipollenites lies fairly distant from Rhoipites angustus and Nyssa, with Momipites more toward the center.

In contrast, the graph from Lake Somerville exhibits a strong gradient on axis 2, with Cupuliferoipollenites and Rhoipites angustus acting as positive and negative end members respectively. Besides Cupuliferoipollenites (+2.2), Cupuliferoidaepollenites (+1.88) scores high on this axis; most taxa score relatively low. These include Momipites coryloides (-.47), Nyssa (-.73), and Rhoipites angustus (-.88). The monocotyledons Arecipites (-.30) and Liliacidites vittatus (-.50) also score negatively on Axis 2. Additionally, the spore taxon Laevigatosporites (+4.51) occurs outside this "gradient" and has a relatively highscore on axis 1. Cicatricosisporites and Microfoveolatosporites also score high on this axis when more taxa are included in the analysis.

The graph of the C Seam composite shows a similar gradient (Text-Figure 24). In this case, Siltaria and Rhoipites angustus are the end members of axis 2. Momipites coryloides (+0.87) and Nyssa (+1.82), in addition to R. angustus (+2.14) score high on axis 2. (Positiveness and negativeness are assigned arbitrarily to any given set of results.) Cupuliferoipollenites scores low (-.83). The monocotyledonous taxon Arecipites, however, scores low (-.60), with Cupuliferoipollenites instead of the Momipites association. Both Laevigatosporites (+4.25) and



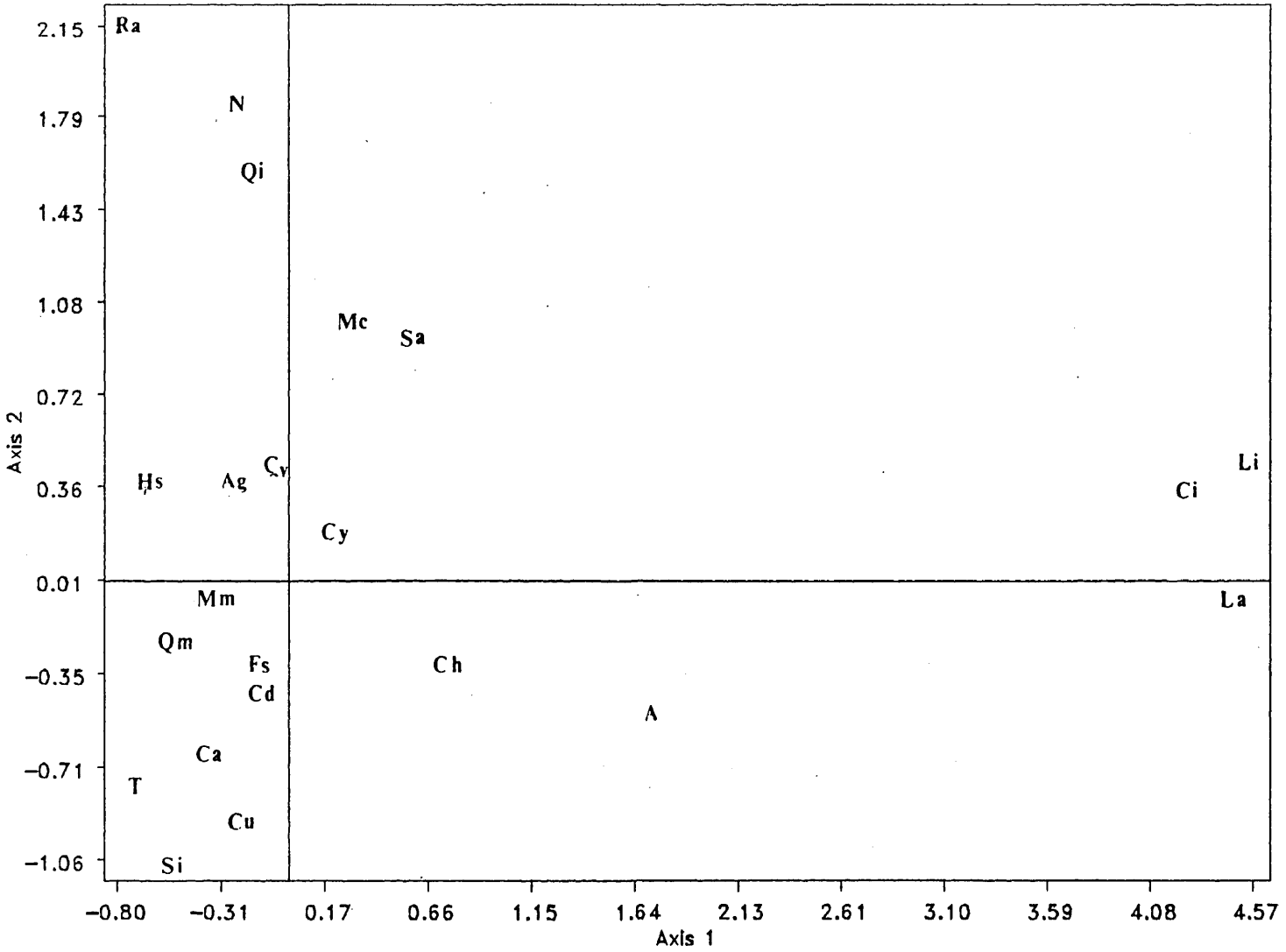

Text-Figure 23. Reciprocal averaging (RA) plot, Sequence C (C Seam) taxa. Abbreviationsare given in Table 6.

Table 8. Synopsis of untransformed RA plots.

| Sequence | Nyssa, Rhoipites, Momipites | Cupuliferoipollenites |
|---|---|---|
| A | Low on axis 2, Nyssa with R. angustus, Momipites near center. | Near center on both axes |
| B | Nyssa and R. angustus high on axis 1, widely separated on axis 2, Momipites near center. | Low on axis 1, centered on axis 2 |
| C | Continuum on axis 1, with R. angustus very negative, Momipites near center. | Very high on axis 1. |
| D | R. angustus very low on axis 1, Nyssa and Momipites at positive middle positions on both axes. | Very low on axis 1, near R. angustus. |
| E | Nyssa and R. angustus high on axis 1, centered on axis 2, Momipites near center. | Near center on both axes. |
| F | Grouped together, high on both axes. | Relatively low on axis 2; high on axis 1. |
| G | Nyssa and R. angustus grouped together, very low on axis 2. Momipites | Moderately low on both axes. |

Table 8. Continued.

| Sequence | Nyssa, Rhoipites, Momipites | Cupuliferoipollenites |
|---|---|---|
| | at center on axis 2, moderately high on axis 1. | |
| H | All negative on axis 1, Momipites closest to center. | Positive on axis 1. |
| Somer-ville | All low on axis 2, Momipites most towards center. (spores form axis 1) | Very high on axis 2. |
| Compound | All high on axis 1, Momipites most toward center. (spores and some palms form axis 1) | Low on axis 2. |



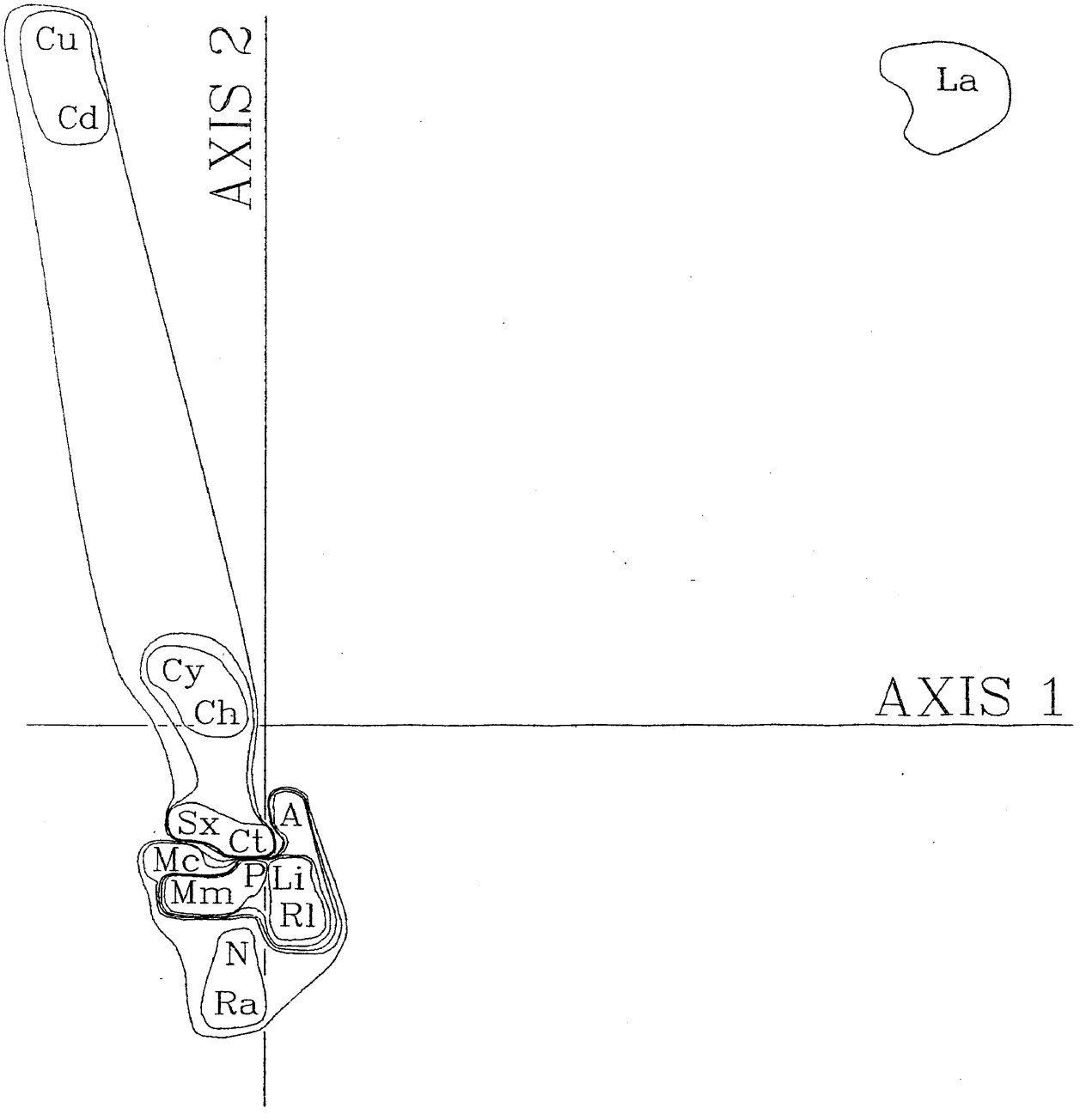

Text-Figure 24. Reciprocal averaging (RA) plot, Composite C Seam samples. Abbreviations are given in Table 6.

Cicatricosisporites (+4.22) score high on axis 1 and are not included in the "gradient."

Examining these graphs together suggests an environmental gradient with this approximate floral sequence: Cupuliferoipollenites, Cupuliferoidaepollenites, Quercoidites microhenricii-Chrysophyllum-small Fraxinoipollenites, Araliaceoipollenites granulatus, Momipites coryloides, Nyssa, Rhoipites angustus.

## Comparison of Reciprocal Averaging with Cluster Analysis

One test of whether a multivariate method yields a valid discriminate of floral associations is to compare the results of those methods used. I transferred cluster analysis groupings from the Pearson product method onto the RA analysis graph of the Lake Somerville lignite samples by drawing curved lines on the RA plot around taxa which successively clustered together (Text-Figure 25). The Pearson Product method separates out Laevigatosporites, also evident in the RA analysis. Cluster analysis is not completely successful at defining the Axis 2 continuum delineated by RA analysis; the Pearson product method separates the species which are high on RA axis two from the majority of taxa, but includes several taxa which scored around zero on Axis 2. Within the large group of taxa which have relatively similar scores low on axis 2, cluster methods pick out some taxa which were adjacent on the RA graph. Several of the cluster diagram pairings join taxa which were relatively widely separated on the RA graph, and larger order pairings do not necessarily join adjacent clusters.



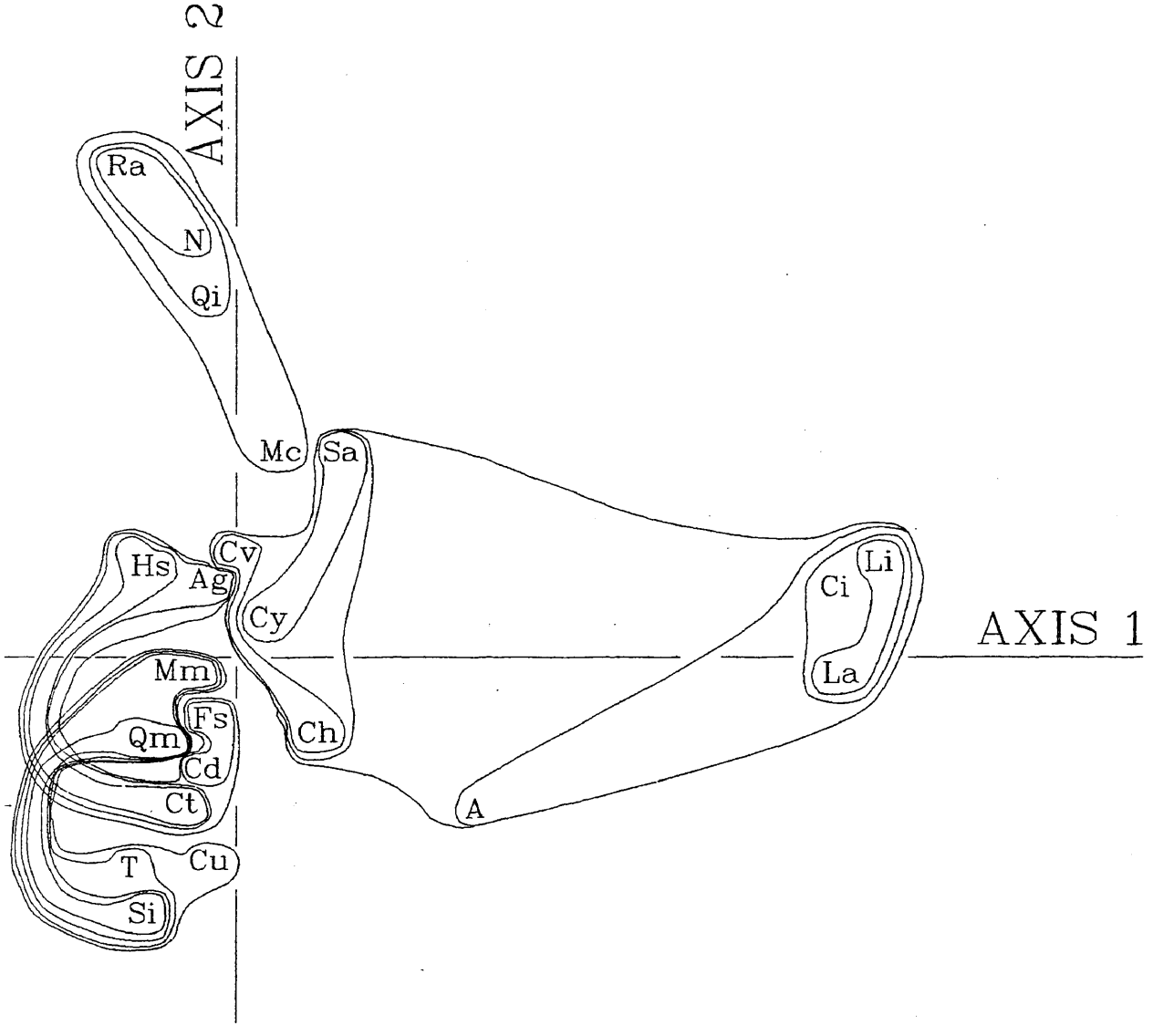

Text-Figure 25. Pearson product cluster analysis groupings superimposed on RA plot of Lake Somerville taxa.

I also compared results of the two cluster analyses of the composite C seam with the RA graph (Text-Figure 26). The cluster diagram is again successful at separating the spore group and at delineating groups which score high on the second RA axis. Within the large group of taxa ranking low on the second RA axis, cluster methods often pick out taxa which are near each other on the RA graph, but larger order associations group taxa which are moderately distant on the RA plot. Cluster analysis splits off a subgroup, defined on the RA graph by adjacent taxa, containing Cyrillaceapollenites sp., C. ventosus and Sabal. Cluster analysis solidly delineates three groups which may have environmental significance: spores, a Cupuliferoipollenites-group, and a group which includes Nyssa, Rhoipites angustus, and Momipites coryloides.

Multivariate analysis of Levels (Seam C)

**San Miguel Sequences.** I ran both Pearson Product Cluster and Reciprocal Averaging Analyses on samples from the C seam of all San Miguel lignite sequences. A composite diagram of the methods was constructed for each sequence. Cluster dendrograms and RA plots are shown in Appendix B.

Both RA and cluster analysis of sequence A split the Cupuliferoidaepollenites-dominated basal sample off from the rest of the C seam. Multivariate techniques further divide the large group of samples from the upperpart of the seam into two parts: the two samples from the top of the seam are separated from the middle four samples which have higher Cupuliferoipollenites percentages.




Text-Figure 26. Pearson product cluster analysis groupings superimposed on RA plot of Composite C Seam taxa.

Both multivariate techniques separate the lower two samples in seam C of sequence B from the top three Cupuliferoipollenites-dominated samples. The two lower samples, one with high Nyssa percentages and the other with high Rhoipites angustus values, lie at opposite ends of axis one of the RA plot.

RA and cluster analysis of the C seam of sequence C both separate out a group consisting of the upper three Cupuliferoipollenites-dominated samples. The lower four samples are grouped into a cluster which has lower Cupuliferoipollenites percentages. Reciprocal averaging further segregates this group into subgroups on the basis of Rhoipites angustus content.

In Sequence D, the uppermost five Cupuliferoipollenites-dominated samples are grouped together by both RA and cluster analysis; sample 250 is only loosely bound to this cluster because of its large percentage of Laevigatosporites. The Momipites coryloides-dominated lower samples also cluster together, although again the Laevigatosporites-Liliacidites dominated sample 280 is only loosely associated with the others.

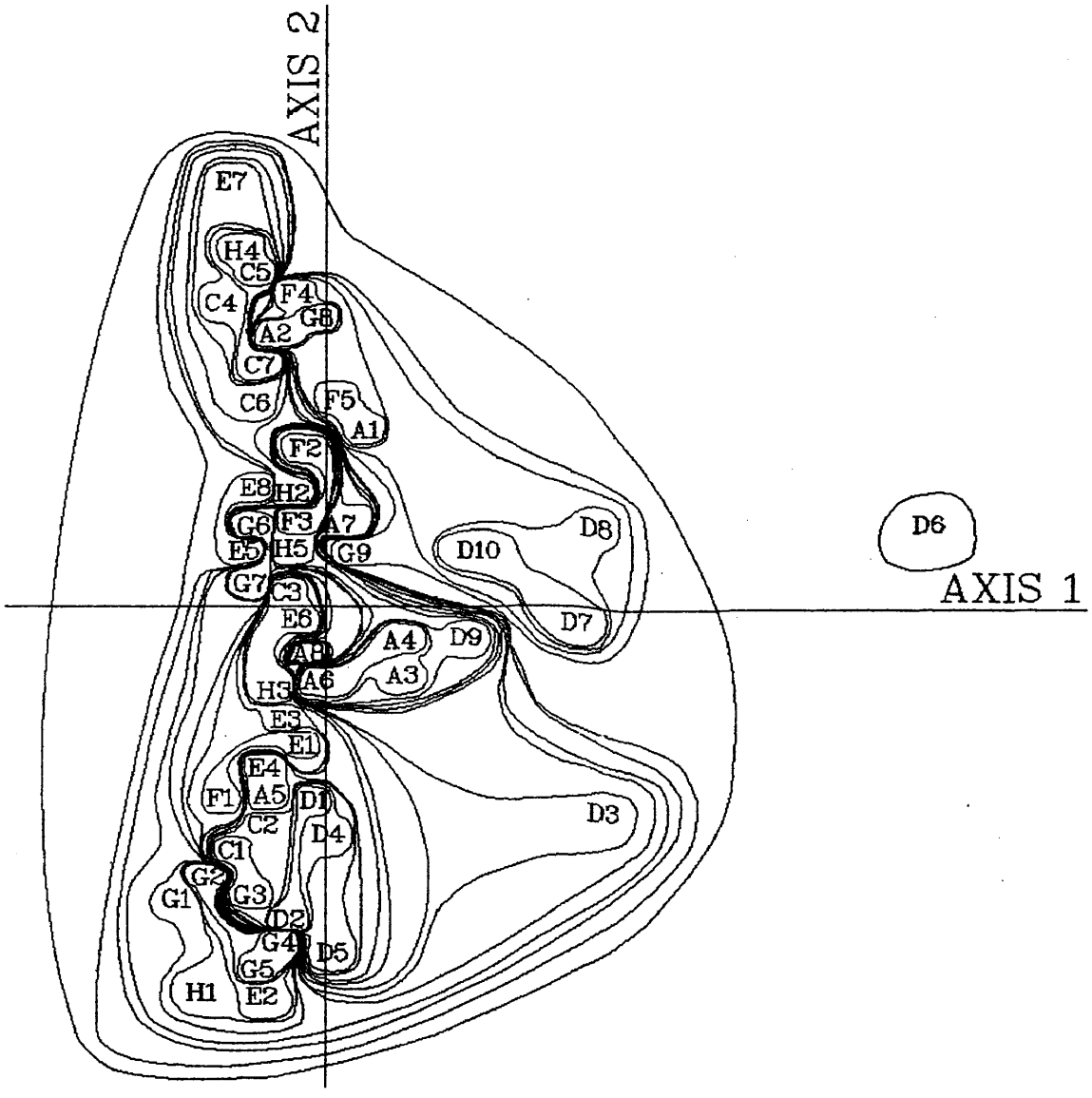
Values from analysis of the C seam of the E sequence do not form groups, but rather a continuum; the cluster analysis grouping generally follows a transect along the RA plot. This transect follows a dominance sequence of Siltaria-Cupuliferoipollenites-degraded small tricolporates-Araliaceoipollenites granulatus-Rhoipites angustus. The positions of Siltaria and Cupuliferoipollenites are switched in the cluster analysis sequence. In general, the basal samples are at the low Cupuliferoipollenites end of the transect. Samples with higher Cupuliferoipollenites values from the upper part of the seam are at the opposite end.

Multivariate analysis separates the uppermost Cupuliferoipollenites-dominated sample of the C seam of sequence F from the rest of the samples. Within the larger group, both methods define a group from the middle of the seam with a moderate amount of Cupuliferoipollenites and a basal group with relatively low Cupuliferoipollenites as well as higher Momipites and Rhoipites angustus percentages. Cluster analysis places the two lowest samples in the latter group, whereas RA places only the lowermost sample in that group.

Samples from the C seam of the G sequence are also segregated into two groups. The lower two samples, dominated by a mixture of Quercoidites microhenricii, Rhoipites angustus, and Momipites coryloides, are loosely connected. The other group generally has a higher dominance by Cupuliferoipollenites. Samples at 40 and 60 cm. have the highest percentage of this taxon and cluster tightly; samples at 10 and 50 cm also cluster in this group. Sample 0 with relatively large numbers of Q. microhenricii and Siltaria clusters with neither subgroup. Another subgroup, composed of samples 70 and 80 from lower in the seam, is set off by intermediate amounts of Momipites coryloides, Quercoidites inamoense, and Rhoipites angustus.

Samples from the highwall (H) sequence also cluster on the basis of Cupuliferoipollenites percentages, but the groupings are not stratigraphically continuous.

**Composite Diagram.** Both cluster analysis and reciprocal averaging were run for the composite sample group composed of all C seam samples, except for those from sequence B (Text-Figure 27). Many of the samples from the D sequence are strewn along RA axis 1, otherwise, the composite set forms an "ecological"



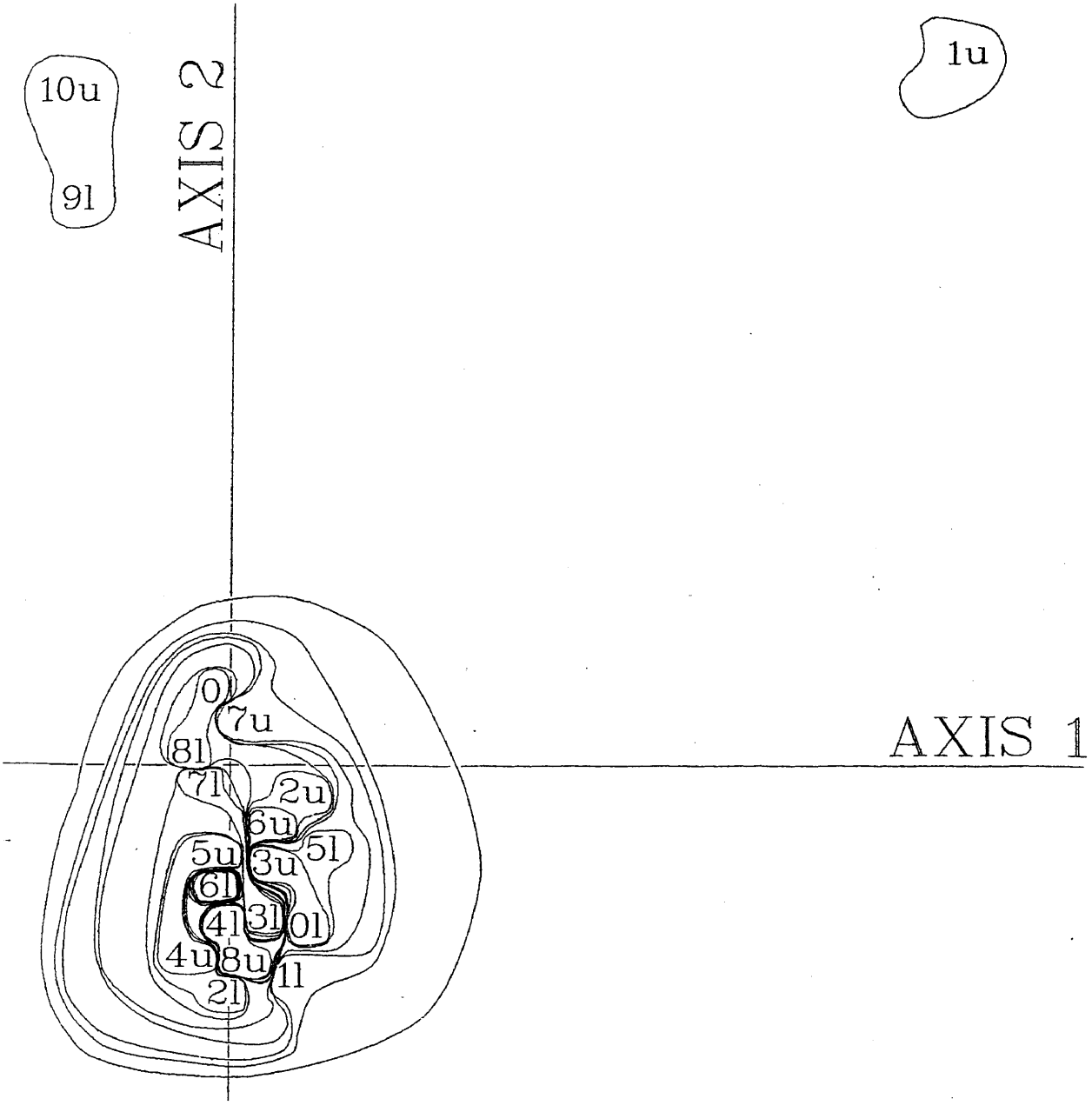

Text-Figure 27. Pearson product cluster analysis groupings superimposed on RA plot of Composite C Seam samples.

continuum along axis two. The D samples differ in that they contain significant amounts of spores as well as Liliacidites.

Cluster analysis splits the composite set into two groups. On the right side of the composite diagram, the lower D sequence samples cluster in a small group with basal samples from sequences F and G and from the top of sequence A. A larger group to the left consists mostly of samples spread along the second RA axis. At the positive end lies a cluster formed from samples from the lower parts of sequences C and E, and two sequence H samples. These samples have fairly high levels of Rhoipites angustus. Two cluster groups lie at the negative end of axis two. One group contains several samples from the upper parts of sequences C and D. These samples are dominated by Cupuliferoipollenites. The other group contains most of the non basal samples from sequence G as well as some samples from sequence H. Cupuliferoipollenites also dominates these samples, but Siltaria percentages are higher. The sample at the base of sequence A, highly dominated by Cupuliferoidaepollenites, clusters in neither group.

**Lake Somerville.** The spore dominated 10U (1u) sample (Text-Figure 28) is segregated both by reciprocal averaging, where it appears alone at one end of the first axis, and by cluster analysis, which "clusters" the sample alone. A well-defined continuum occurs along RA axis two between Cupuliferoipollenites dominated samples, and levels with a mixed flora.

Cluster analysis further separates a cluster with relatively high percentages of Liliacidites, including samples 0L, 50L, and 30U within a cluster of many samples at the "mixed flora" end of axis 2. All these




Text-Figure 28. Pearson product cluster analysis groupings superimposed on RA plot of Lake Somerville samples.

"mixed flora" samples have relatively high Momipites coryloides percentages.

**Discussion.** Most of the multivariate diagrams of individual C seams split the samples into an upper and lower group on the basis of Cupuliferoipollenites percentages. Two sequences are without definite clusters, but a continuum with high Cupuliferoipollenites percentages nevertheless exists.

The composite C seam multivariate diagram (Text-Figure 27) indicates that there are three types of seam base floras. One group contains spectra from sequence D, F and G; another from A; and the third from C and E. Slightly to conspicuously higher Momipites coryloides percentages is the most obvious delineator of the first group. The unusually high basal percentage of Cupuliferoipollenites sets apart the second. The third group consists of samples with higher Rhoipites angustus percentages.

The continuum along RA axis one indicates that an environmental gradient may be represented within the samples. There is no reason to believe that all palynomorph sequences would travel the same temporal path through the gradient. The multivariate plot indicates that they did not do so: some seamtops and seambases are positioned at the ends of axes, but others are not. In any case, two basic continuums are suggested. One continuum features high Cupuliferoipollenites grading to high Rhoipites angustus or Momipites coryloides percentages. The other continuum changes gradually from this R. angustus-Cupuliferoipollenites based assemblage to one dominated by spores and Liliacidites.

This same scheme is present in the Lake Somerville sequence. Samples with high Cupuliferoipollenites

percentages lie at one end of axis two, with samples high in Momipites coryloides and other taxa at the other end. One sample high in spores clusters at the other end of axis one.

## Efficacy of the Multivariate Technique

Multivariate techniques tended to substantiate and reinforce the floral and sample relations which I noticed in the samples. Both observation and multivariate techniques found the oppositional relationship in the San Miguel lignites and at Lake Somerville of samples high in Cupuliferoipollenites and samples high in Rhoipites angustus and Nyssa. Observation showed a strong difference between basal samples with high M. coryloides and those with high R. angustus percentages. Observation did not show the importance of Cupuliferoipollenites-dominated samples with high percentages of Siltaria. Neither did it indicate the importance of Liliacidites and spores as an oppositional assemblage.

Because both methods indicated the same end member taxa, however, observation and multivariate analysis divided individual C seam sequences in the same general manner.

## Horizontal Sequences

Few experienced palynologists interpret "pollen" diagrams literally. The factors which potentially lead even Quaternary palynologists astray are many, and are described by Moore and Webb (1978). For a palynologist

interested in generalized or regional interpretations, one of the pitfalls is the lateral, local variations in pollen spectra. These variations are particularly evident in wetlands where much of the pollen rain is local: modern pollen percentages vary considerably within a few meters in surface samples from wetlands. For example, Griffin's (1975) study of the Red Lake peatlands of Minnesota shows differences of 30 and 42% for Acer and 30 and 312% for Betula (not included in Griffin's pollen sum) in samples taken about 12 m apart in larch forest.

For a palynologist interested in microenvironmental change, however, these lateral changes are advantageous. Birks and Gordon (1985) comment:

> Answers to the question of where particular plant communities grew in the past are critically dependant on our knowledge and understanding of the complex processes of plant transport and dispersal and on the choice of site, particularly in size and potential pollen source area...Pollen sequences from several sites within a small geographical area are required to detect patterns of vegetational differentiation related, for example, to altitude,...and to climate and topography... Alternatively, transect of pollen diagrams across a site either in one...or two...dimensions may permit the detection of spatial differentiation in the occurrence of particular pollen assemblages and hence particular plant communities...(p. 9).

The vertical palynomorph sequences from San Miguel are fortunately representative of a paleotransect, and the palynomorph diagrams do show some striking differences. This opportunity for interpretation of local paleoenvironments will be exploited in the chapter entitled "Paleoecology."

**Sampling Methods.** In order to estimate of the amount of lateral variability in the San Miguel lignite, I collected horizontally spaced samples from the highwall section in addition to those vertical samples

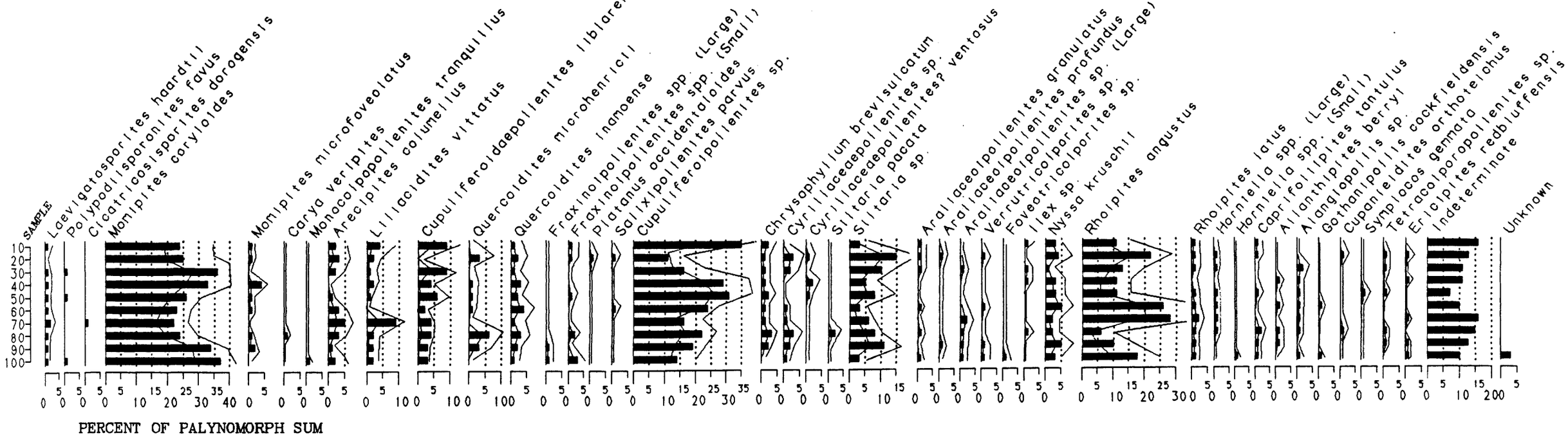
designated as Sequence H (Text-Figure 11). Ten "Mini" samples from the base of the C seam were collected at 10 cm intervals beginning with the basal sample of sequence H. Additional basal samples ("Seambase") were taken at points coinciding with Sam Gowan's "flags," representing intervals of approximately 6 m. A third sample set ("Ash") was taken from lignite immediately above the ash layer pictured by Gowan (1985), also taken at approximately 6 m intervals coinciding with Gowan's "flags." The samples were processed and counted according to procedures outlined in the Methods chapter. Some samples had statistically inadequate pollen counts; these data were not used.

**Methods and Results: Introduction.** Palynomorph diagrams of the three horizontal sequences are shown, with confidence intervals, in Text-Figures 29-32. These diagrams indicate that percentage values vary systematically rather than randomly along the traverse. There is some indication from these curves that Momipites varies conversely with Rhoipites angustus. The variation may be due, as suggested by Turner et al. (1989), to differential pollen preservation, or to systematic differences in pollen deposition within microenvironments. In any case, the large horizontal variations in percentages in the closely-spaced San Miguel lignite samples imply that many vertical changes in the palynomorph curves are likely to be meaningless.

I used several different statistical methods to determine whether taxon proportions in these horizontal samples varied more or less than the percentages in the vertical sequences.

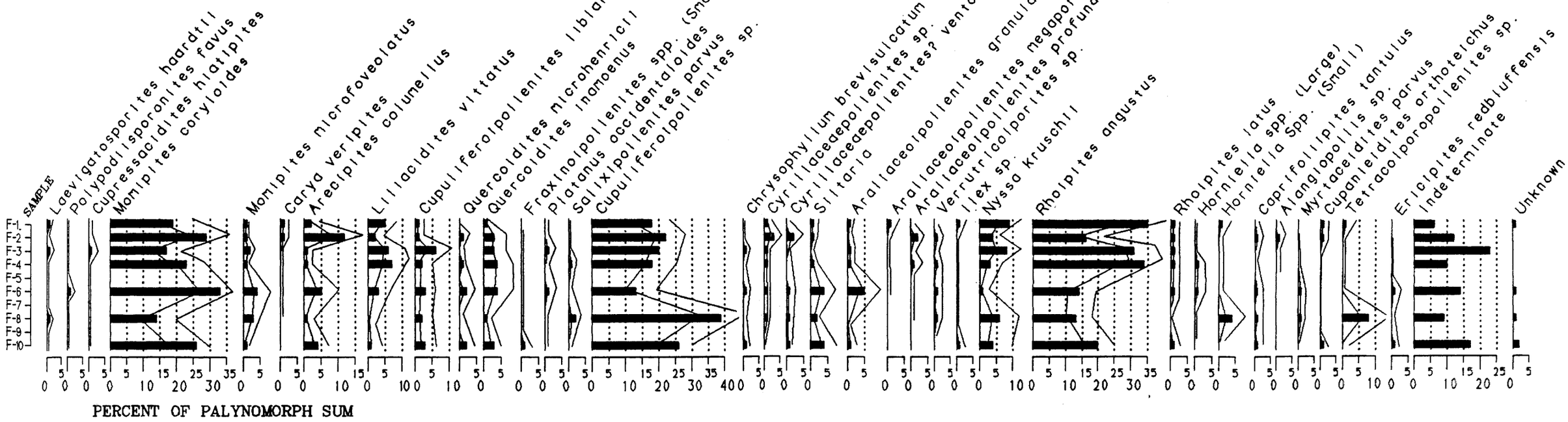
**Methods and Results: Confidence Intervals.** The concept behind confidence intervals is discussed by Moore and Webb (1978) and by Birks and Gordon (1985).

"MINI" SEQUENCE
SAN MIGUEL HIGHWALL



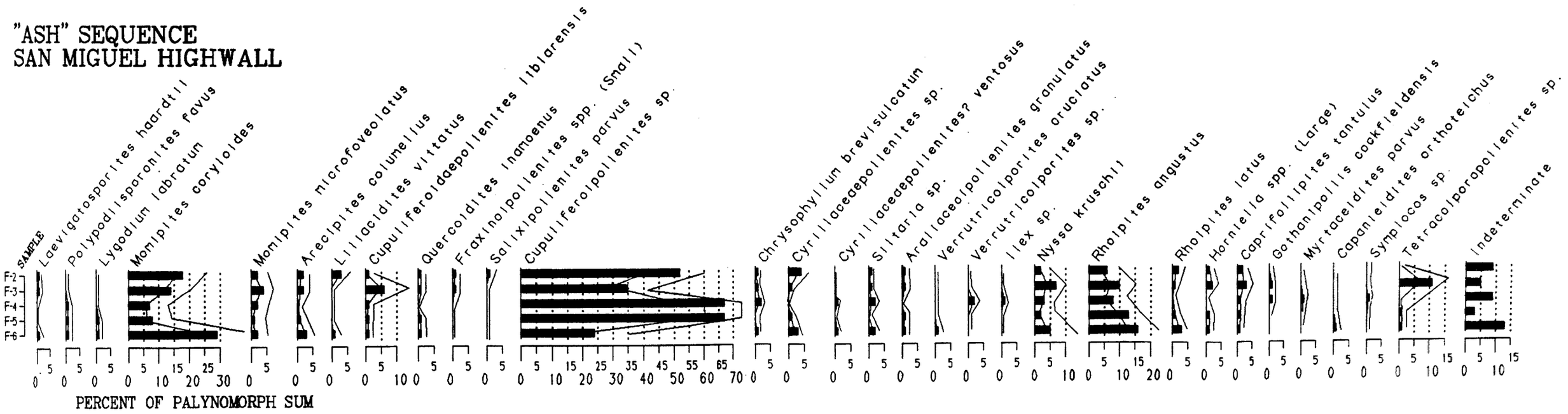

Text-Figure 29. 95% confidence intervals, Mini samples.

"SEAMBASE" SEQUENCE
SAN MIGUEL HIGHWALL



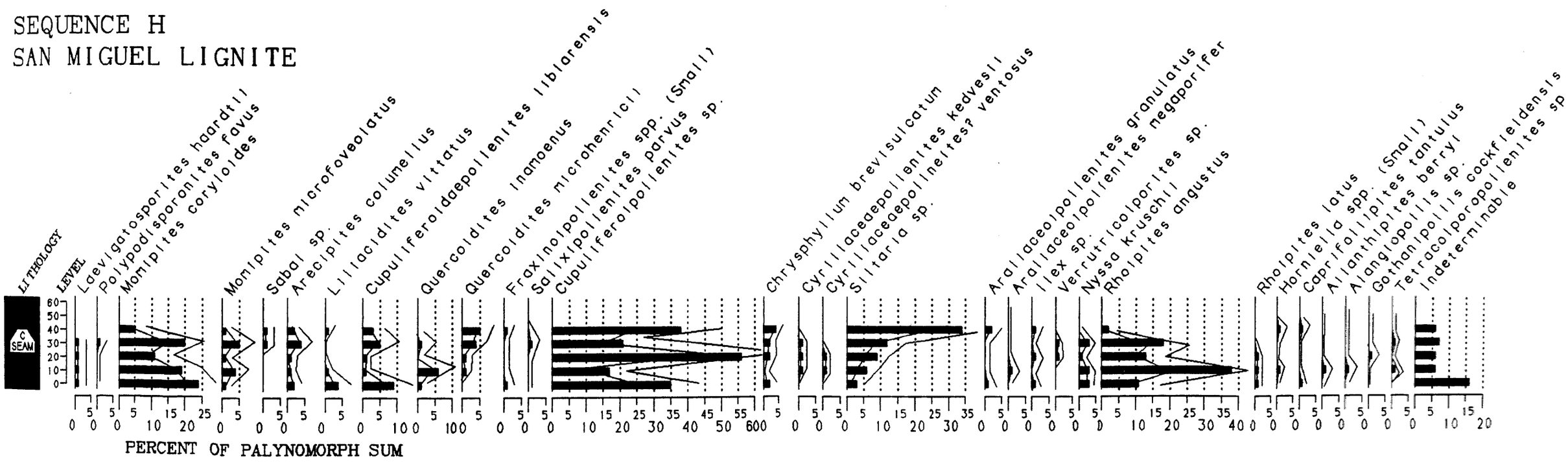

Text-Figure 30. 95% confidence intervals, Seambase samples.

"ASH" SEQUENCE
SAN MIGUEL HIGHWALL




Text-Figure 31. 95% confidence intervals, Ash samples.

SEQUENCE H
SAN MIGUEL LIGNITE




Text-Figure 32. 95% confidence intervals, Sequence H.

By necessity, only a small proportion of the palynomorphs in a given sediment sample can be counted. The percentages derived from these counts are in reality estimates of the true proportion of each taxon present in the sample. A 95% confidence interval is constructed around the counted, or "estimated" value; there is a 95% chance of the "true" value being included within this interval. A "true" value would have a 99% chance of being included within a 99% confidence interval, which is much wider than a 95% confidence interval. Sample size is an important component of these equations; the confidence limit narrows as sample size increases.

Confidence intervals have been used by a number of palynologists to evaluate the statistical validity of the variations in pollen curves. In a pioneering work, Maher (1972) included confidence intervals for every taxon present in his pollen diagram of Quaternary sediments from Colorado. Maher explained how to interpret his diagrams: "In general, if the point estimate or estimate of either sample is included in the 95% confidence interval of the other, the two samples will not be found to differ significantly at the 0.05 level. But if the point estimate of neither of the samples is included in the 0.95 confidence interval of the other, the two samples will be found to differ significantly at the 0.05 level." This differs from Moore and Webb's (1978) explanation, which implies that taxon percentages with confidence intervals that do not overlap are statistically different at that level of confidence.

Maher unfortunately did not interpret his profiles in the light of confidence intervals, but his superpositions of confidence intervals on pollen profiles imply that many of his intrazonal variations are not statistically significant. Since then, only a few authors have

included confidence intervals in pollen diagrams. It remains, however, a useful technique for comparing counts of different sizes and for discerning the importance of percentage fluctuations.

In this paper, I use a slightly simplified equation for the 95% confidence interval given by Moore and Webb (1978):

$$95\%CI = \frac{\hat{p} + \frac{3.84}{2n} \pm (1.96)\sqrt{[\hat{p}(1-\hat{p})/n] + [3.84/(4n^2)]}}{1 + [3.84/n]}$$

p is the proportion of grains counted and n is the pollen sum.
This equation is used for taxa within the palynomorph sum.

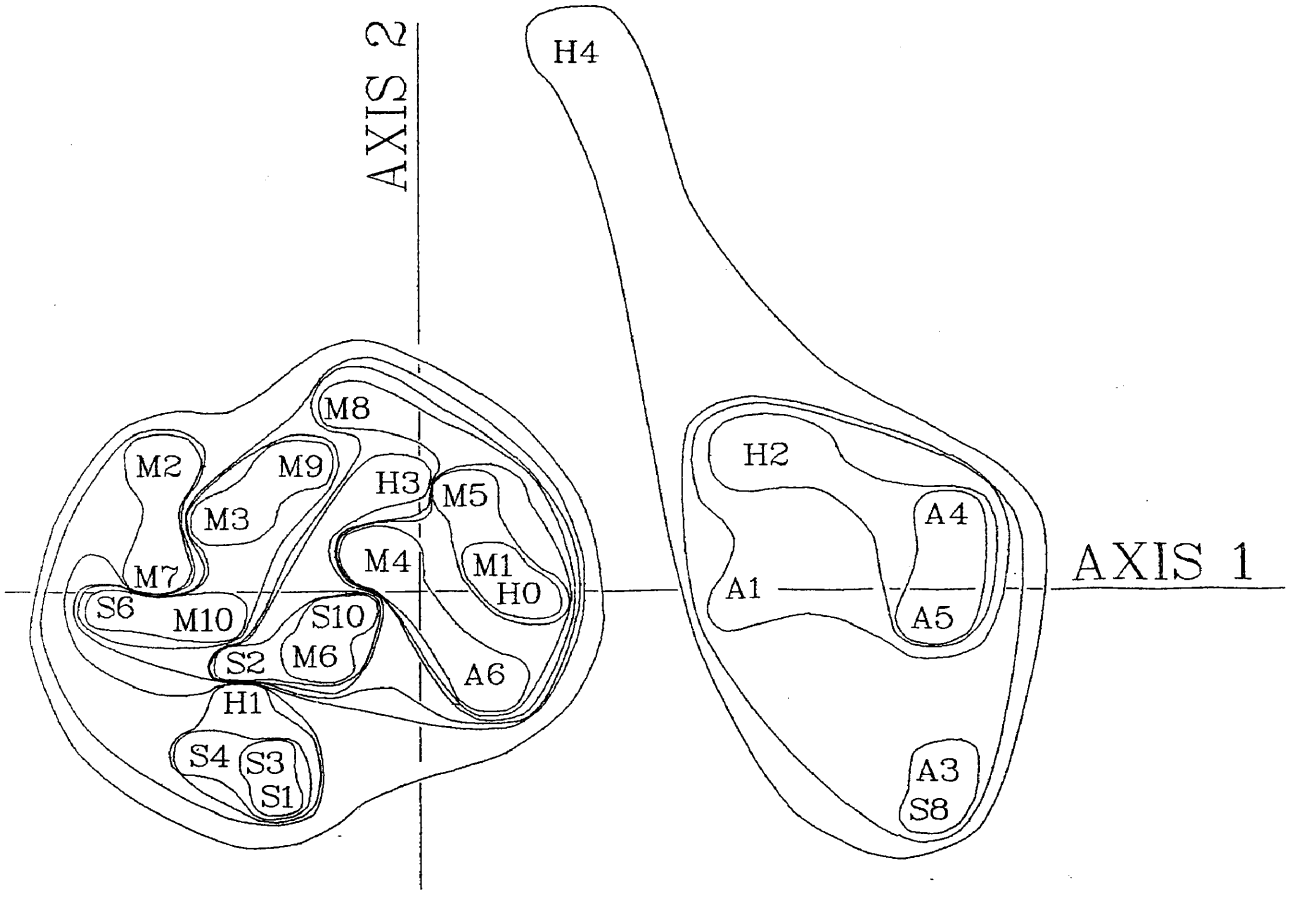
Confidence intervals have been superimposed on the diagrams for the three horizontal sample sequences and the vertical sequence (Text-Figures 29-32). These diagrams are not particularly helpful in determining whether the vertical changes in Sequence H are valid. In each of the highwall horizontal traverses, no major taxon emerges statistically equal in all samples. In the Mini sequence, where samples are only 10 cm. apart, palynomorph spectra seem no more likely to be statistically the same than in the Seambase sequence where the samples are 6 m apart. When 95% confidence intervals for the vertical highwall sequence are plotted, most major taxa are likely to have some statistically different data points; conversely, other taxa such as Nyssa have percentages which are statistically the same through the sequence H diagram. The use of 95% confidence intervals indicates that there are statistically significant differences between samples in both the vertical and horizontal sequences,

but does not indicate the relative importance of these differences.

**Methods and Results: Multivariate Analysis.** One of the few papers which examines variability over a short distance is by Turner et al. (1989). These authors compared pollen spectra from two Holocene blanket peat sections from the North York Moors of England. The sections were dug 30 cm. apart, and samples were removed every cm. After pollen analysis, Turner and her colleagues separated the profiles into zones, figured taxon averages for each zone, and grouped these averages using DECORANA (detrended correspondence analysis), a multivariate technique similar to reciprocal averaging. They found that "...the differences between the two diagrams are small relative to the differences between zones." (p. 416)

I ran both reciprocal averaging (correspondence analysis) and Pearson product moment cluster analysis for all the highwall samples. A composite diagram of these two methods is shown in Text-Figure 33.

There are basically two groups in the composite diagram. One large group contains mostly samples from the two basal sequences as well as from the lower part of the vertical highwall sequence (H). The other much smaller group contains samples from the ash layer and two vertical sequence samples, as well as one sample from the Seambase series. The latter group is defined by higher levels of Cupuliferoipollenites. Within the larger group, most of the Mini (10 cm.) samples are located close together on the RA plot, as are most of the Seambase samples. Cluster analysis groups some Mini samples closer to Seambase samples. Both methods cluster one Ash sample with the Mini samples. These changes include not only fluctuations between two




**Text-Figure 33. Results of Pearson product cluster analysis superimposed on Reciprocal Averaging plot, Highwall samples.**

statistically equivalent percentages, but also changes of larger magnitude. Conversely, the successful grouping of horizontal sequences, as well as the results of Turner et al, suggests that changes which occur in the vertical sequences and which are consistent between sequences can be interpreted as "real." Larger scale percentage changes which occur in only one sequence likely represent "real" changes in the local vegetation. Grouping the samples of a given sequence using multivariate techniques may prove useful for determining valid large scale vegetational events (see the chapter on Multivariate Analysis of Samples).

**Methods and Results: Running Averages.** "Running averages" is a simple statistical procedure which smooths data and removes "noise" (and possibly some of the data as well) by averaging data from several adjacent levels. The formula for a three sample unweighted running average is:

$$R = \frac{P_{(i-1),k} + P_{i,k} + P_{(i+1),k}}{3}$$

P is the percent counted for sample i, k.

Running averages are not often used by palynologists. Birks and Gordon (1985) recommend against the method because they believe an a priori knowledge of the structure of the data is necessary to use this technique for primary data. Nevertheless, running averages have been used by a few palynologists; for example, Ritchie (1982) used the technique to cut out excessive noise in Quaternary pollen concentration data from the Yukon.

In this study, I have used confidence intervals of running averages of three taxa, Momipites coryloides,

Cupuliferoipollenites, and Rhoipites angustus, to graphically compare palynomorph variability in the eight vertical sequences through the C and D seams and through the overburden of sequence E, as well as in the closely spaced vertical "Mini" samples from the San Miguel highwall. Several types of running averages exist. I used a three sample running average because it provides the minimal amount of "smoothing" necessary for the confidence intervals of all three taxa in samples from the horizontal "Mini" sequence to at least touch one another and be considered identical. I also averaged the sums used in the calculation of confidence intervals. Results of the averaging of the C seam of the sample sequences are summed up in Table 9.

Within the horizontal sequence (Text-Figures 34-36), averaged percentages of Rhoipites angustus exhibit the most variability; the 95% confidence intervals of samples "60" and "90" barely coincide with one another (Text-Figure 36). Larger segments of the confidence intervals of the other two taxa coincide with those from all other samples. Percentages of R. angustus are unusually high in these seam base samples.

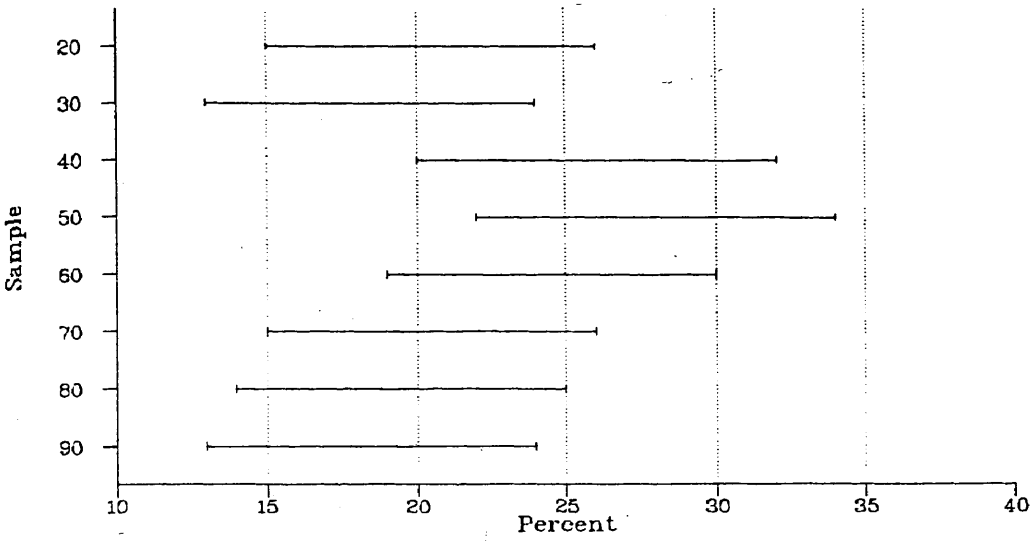
The 95% confidence intervals for taxa in the clastic overburden samples are most uniform (Text-Figures 37-39), more so than for taxa in the horizontal samples. Overlap of confidence intervals is substantial for all three taxa, but is greater for Cupuliferoipollenites and Momipites coryloides than for Rhoipites angustus. For all three taxa, there are no samples which cannot be considered "statistically the same" as any other sample.

In contrast, variability is greater for the vertical sequence (Text-Figures 40-63) in all the lignite seams analyzed than for the Highwall horizontal sequence. The variability is most noticeable for

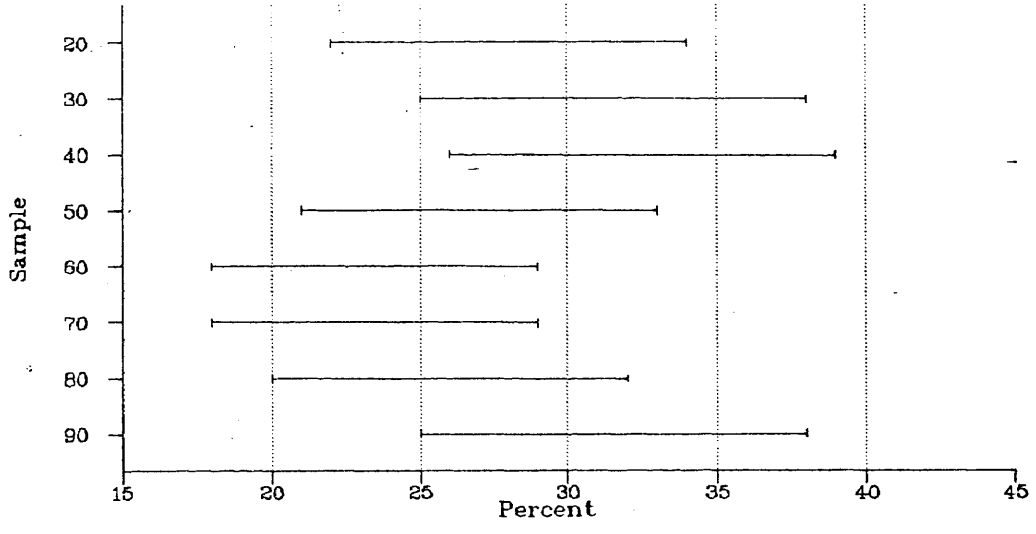
Table 9. Synopsis of confidence intervals of running averages, vertical sequences.

| | | C Seam | |
|---|---|---|---|
| Seam | Momipites | Cupuliferoipollenites | Rhoipites |
| A | | S | S |
| B | | S | S |
| C | | S | S |
| D | S | S | |
| E | S | S | S |
| F | | S | |
| G | S | S | S |
| H | | S | |
| | | D Seam | |
| B | S | S | S |
| C | S | S | S |
| D | | S | S |
| E | S | S | |
| F | S | S | S |
| G | S | S | S |

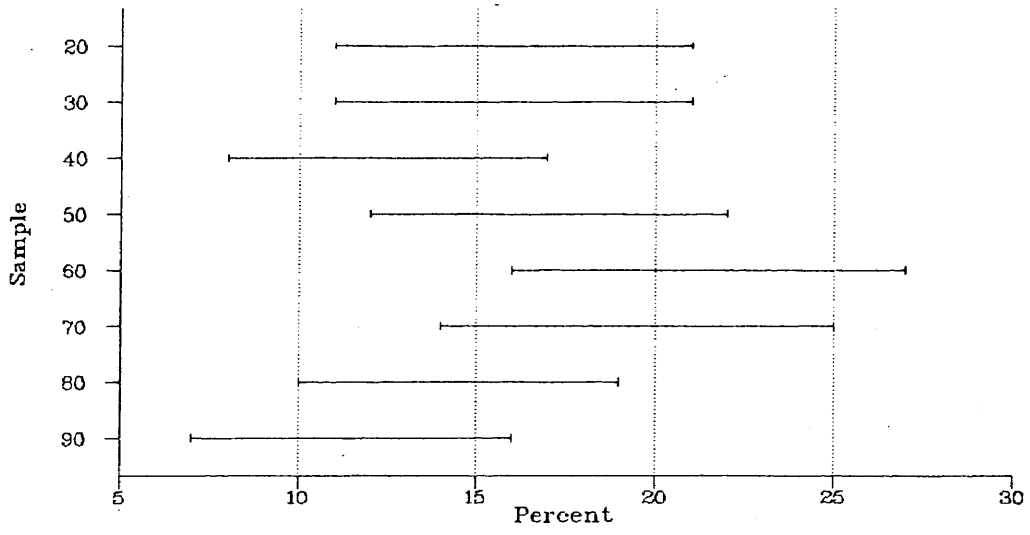
S="Statistically Significant"



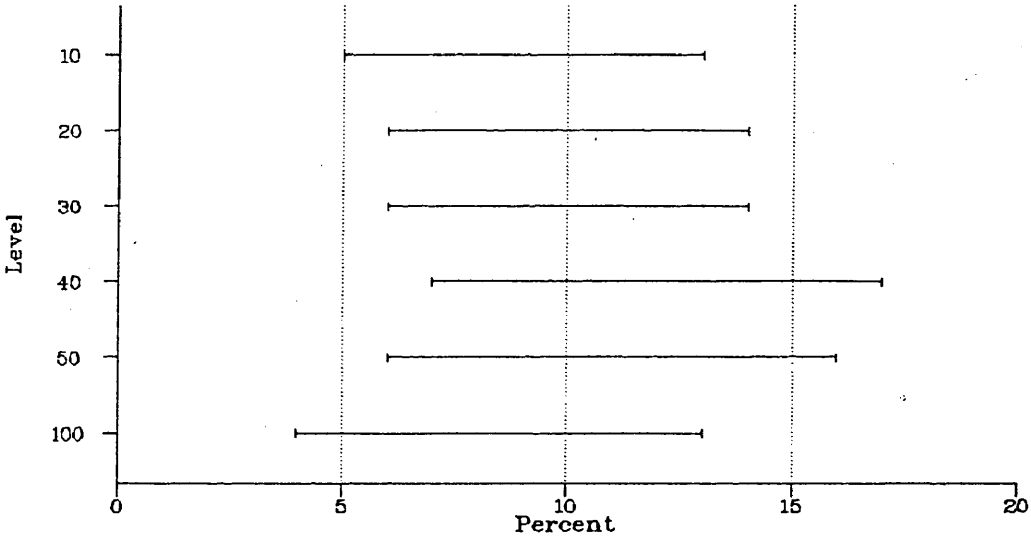

Text-Figure 34. 95% confidence intervals for running averages of Cupuliferoipollenites percentages, horizontal highwall "Mini" samples.



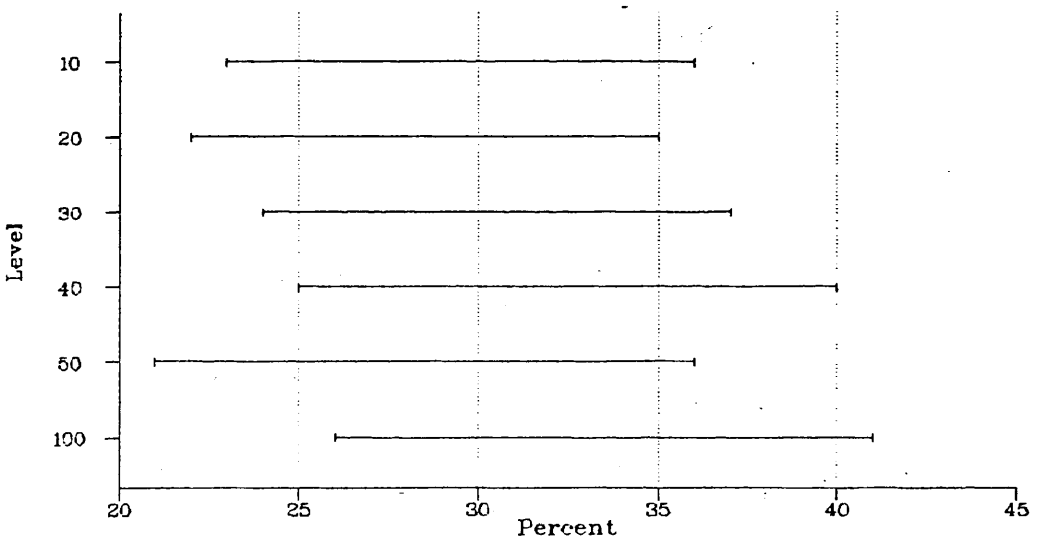

Text-Figure 35. 95% confidence intervals for running averages of Momipites coryloides percentages, horizontal highwall "Mini" samples.



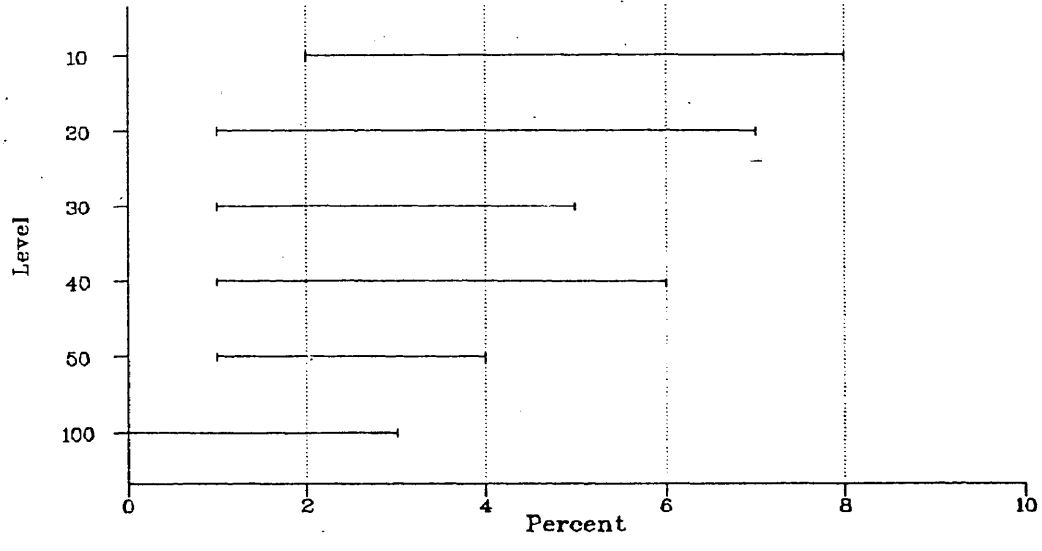

Text-Figure 36. 95% confidence intervals for running averages of Rhoipites angustus percentages, horizontal highwall "Mini" samples.



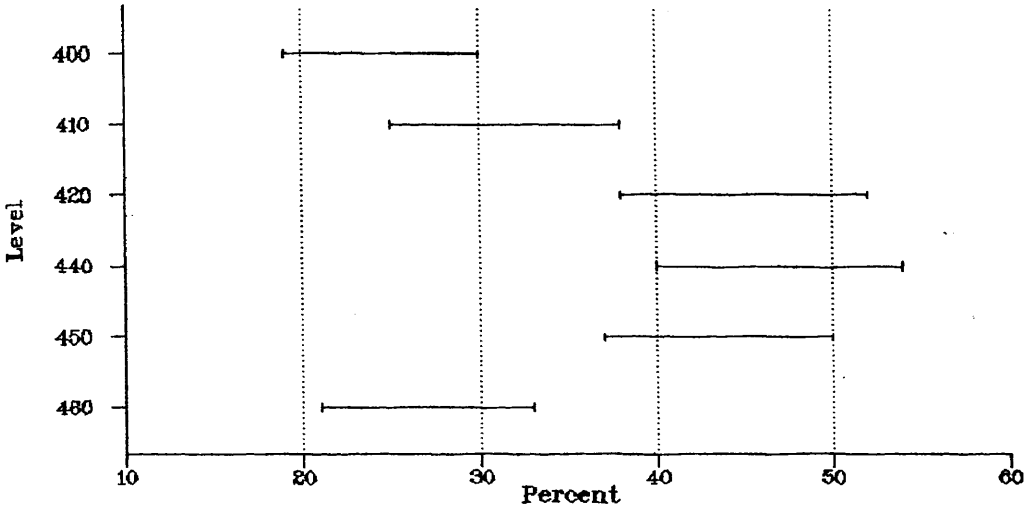

Text-Figure 37. 95% confidence intervals for running averages of Cupuliferoipollenites percentages, overburden of Sequence E.



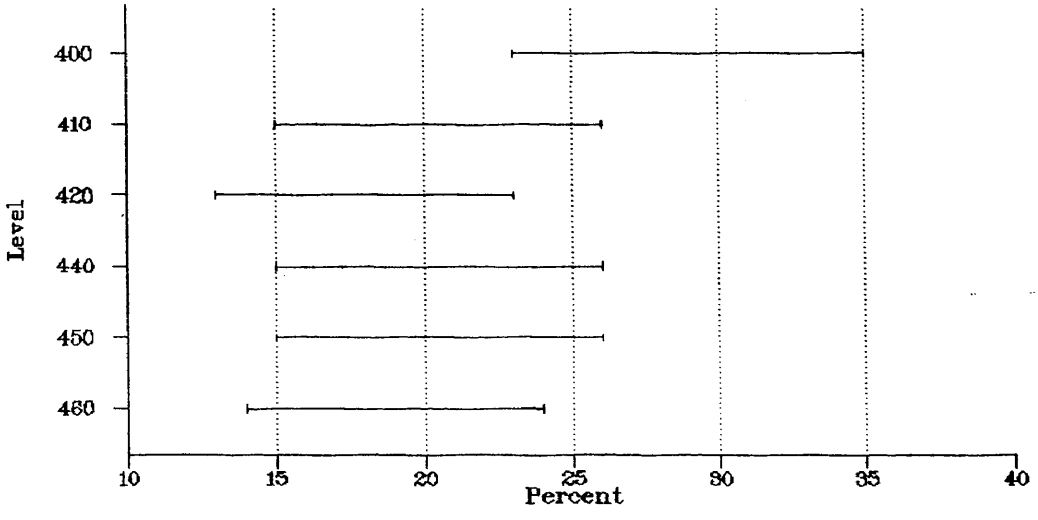

Text-Figure 38. 95% confidence intervals for running averages of Momipites coryloides percentages, overburden of Sequence E.



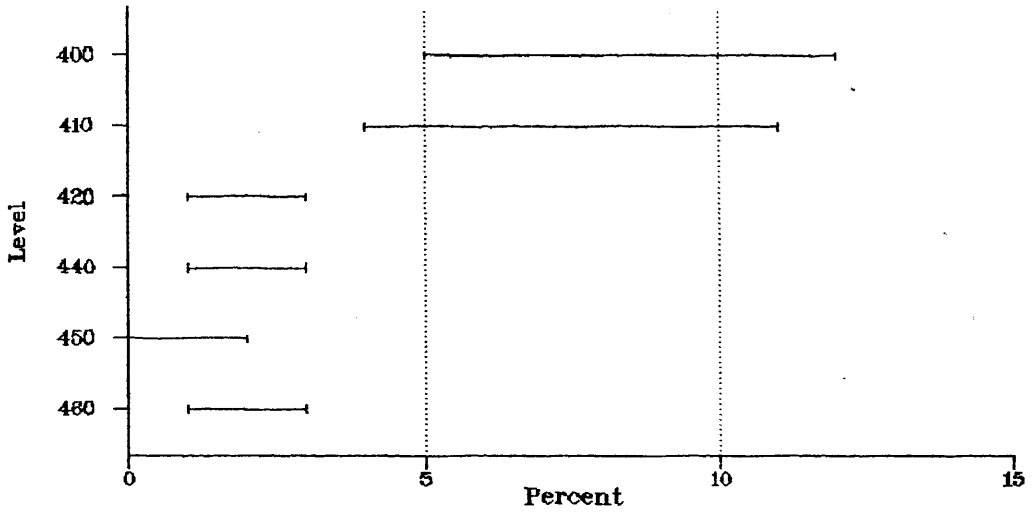

Text-Figure 39. 95% confidence intervals for running averages of Rhoipites angustus percentages, overburden of Sequence E.



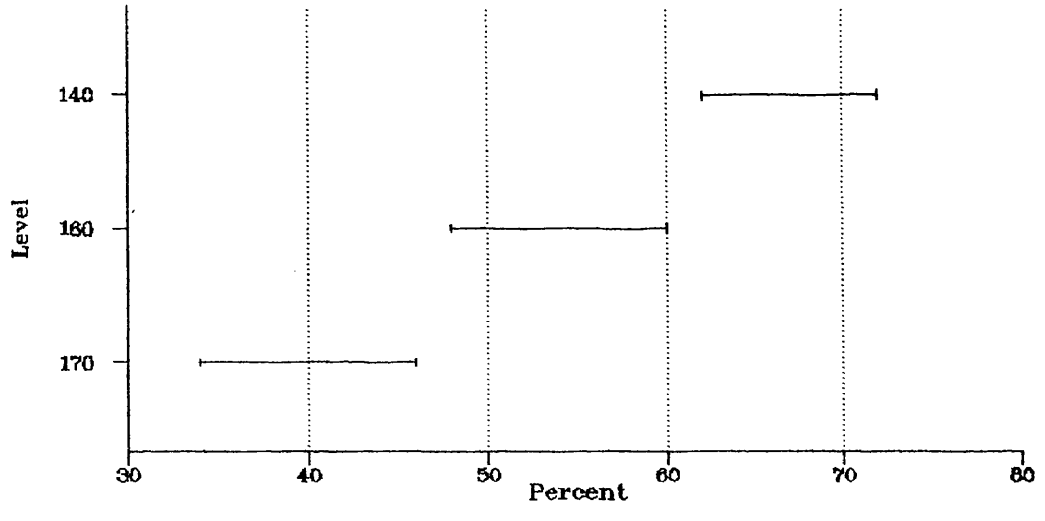

Text-Figure 40. 95% confidence intervals for running averages of Cupuliferoipollenites percentages, C seam of Sequence A.



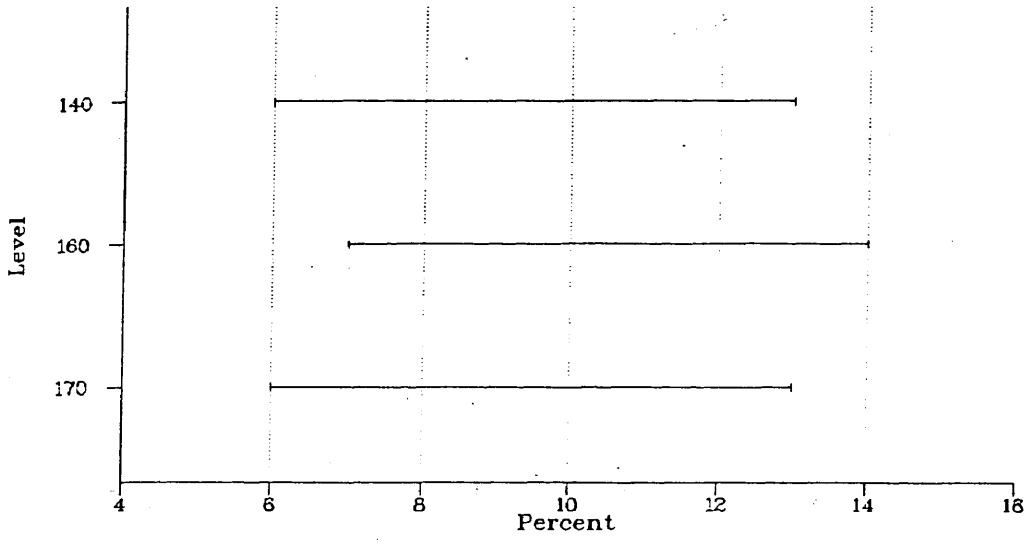

Text-Figure 41. 95% confidence intervals for running averages of Momipites coryloides percentages, C seam of Sequence A.



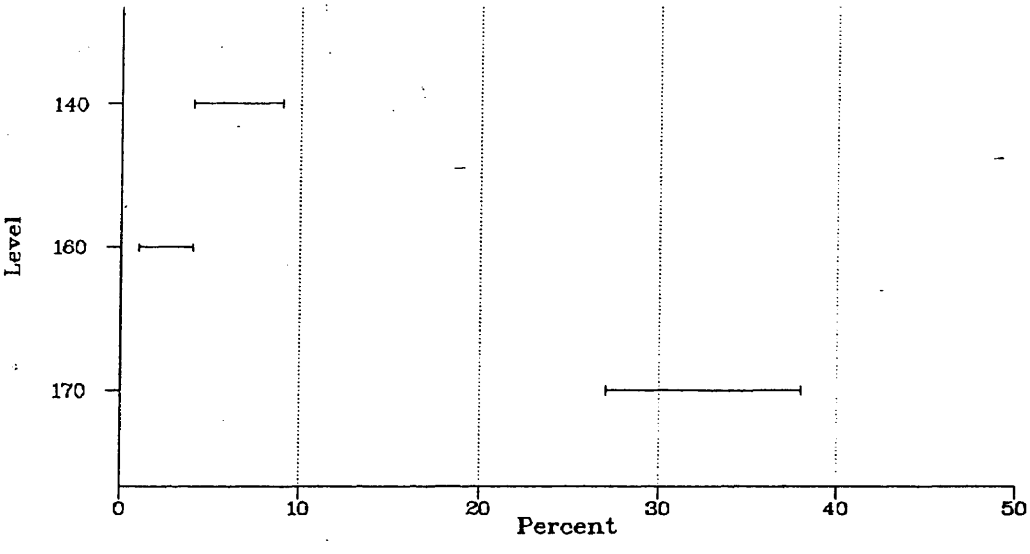

Text-Figure 42. 95% confidence intervals for running averages of Rhoipites angustus percentages, C seam of Sequence A.



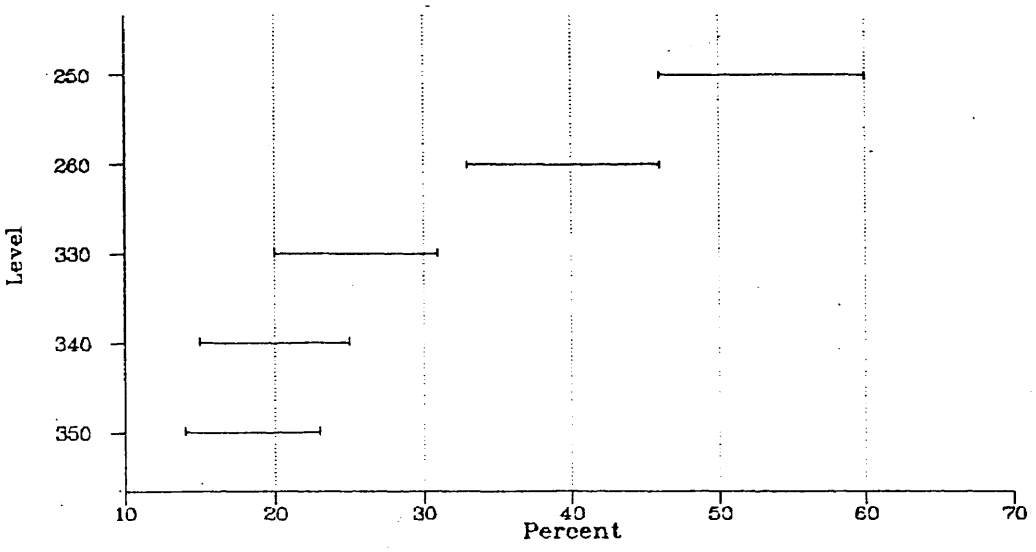

Text-Figure 43. 95% confidence intervals for running averages of Cupuliferoipollenites percentages, C seam of Sequence B.



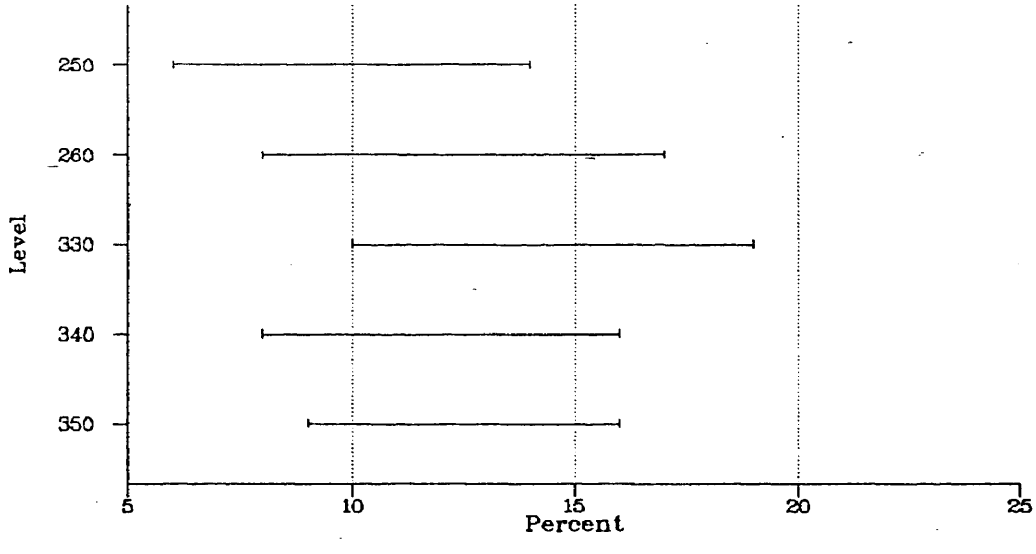

Text-Figure 44. 95% confidence intervals for running averages of Momipites coryloides percentages, C seam of Sequence B.



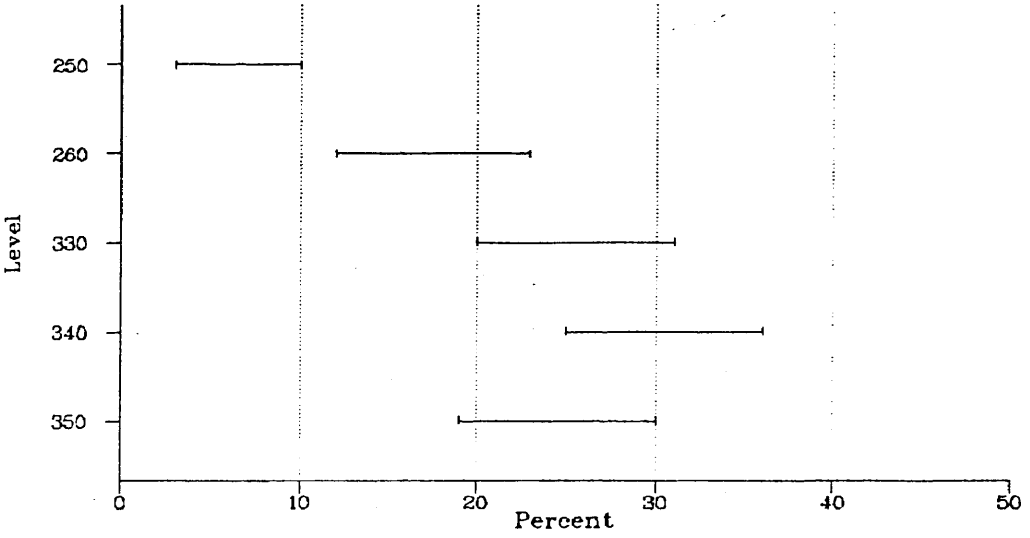

Text-Figure 45. 95% confidence intervals for running averages of Rhoipites angustus percentages, C seam of Sequence B.



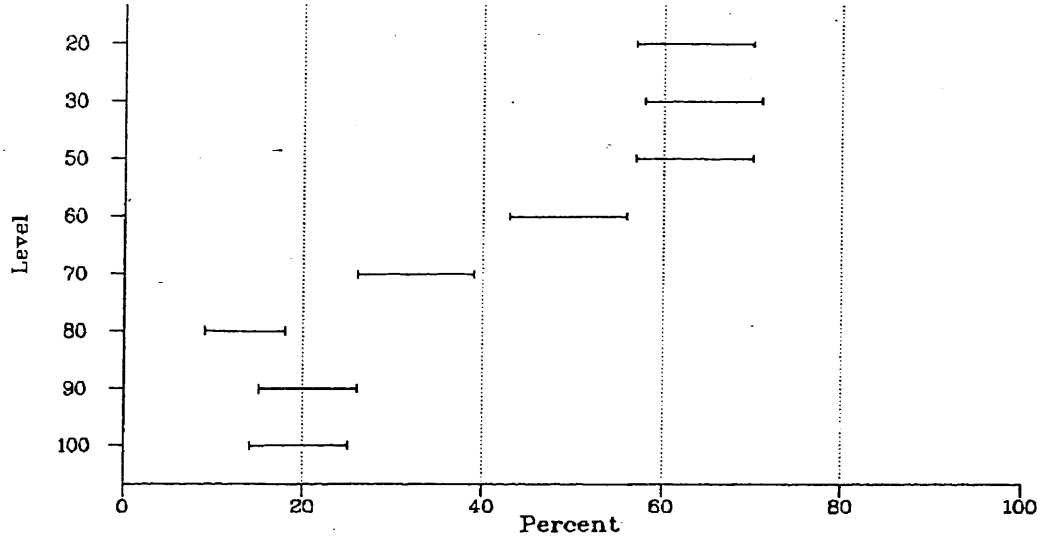

Text-Figure 46. 95% confidence intervals for running averages of Cupuliferoipollenites percentages, C seam of Sequence C.



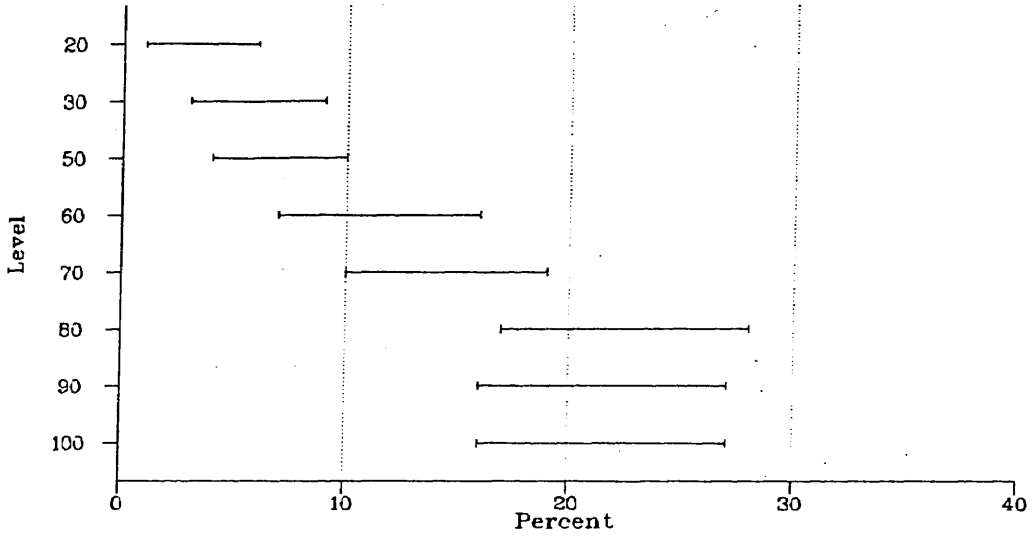

Text-Figure 47. 95% confidence intervals for running averages of Momipites coryloides percentages, C seam of Sequence C.



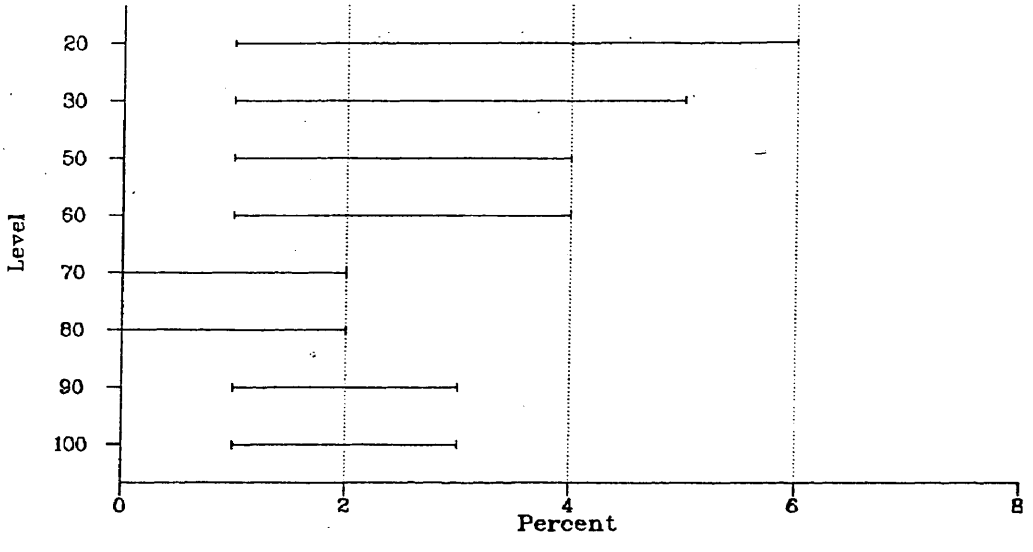

Text-Figure 48. 95% confidence intervals for running averages of Rhoipites angustus percentages, C seam of Sequence C.



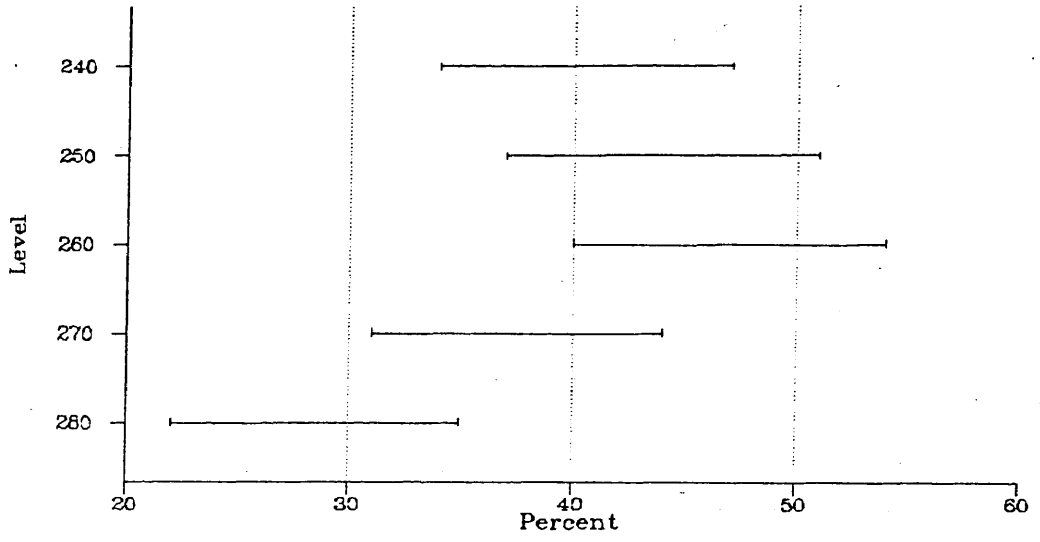

Text-Figure 49. 95% confidence intervals for running averages of Cupuliferoipollenites percentages, C seam of Sequence D.



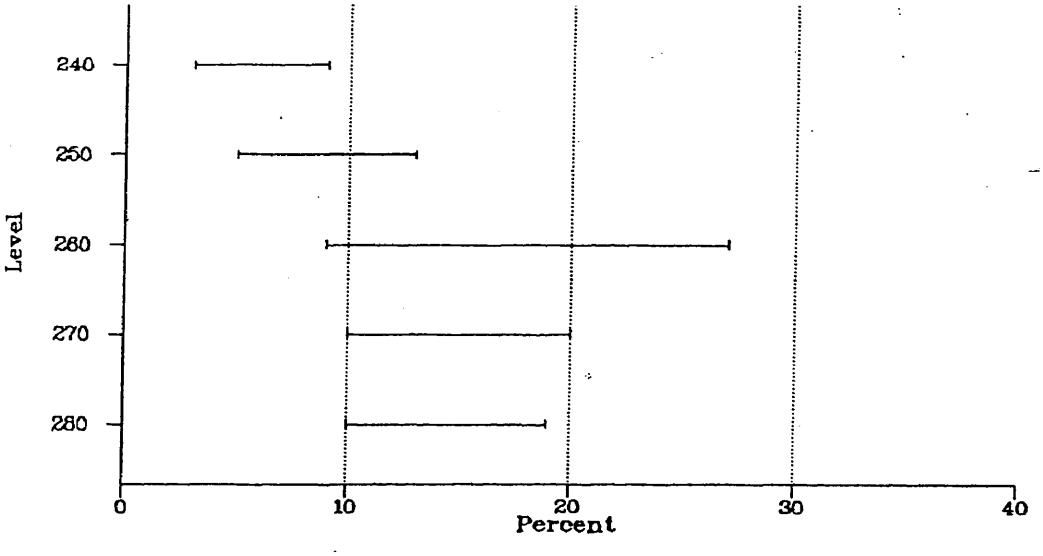

Text-Figure 50. 95% confidence intervals for running averages of Momipites coryloides percentages, C seam of Sequence D.



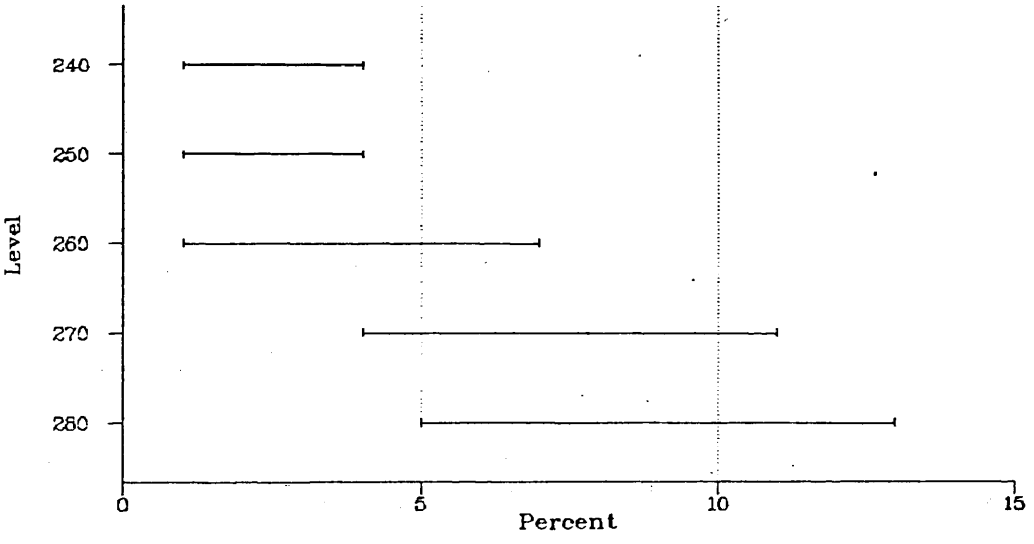

Text-Figure 51. 95% confidence intervals for running averages of Rhoipites angustus percentages, C seam of Sequence D.



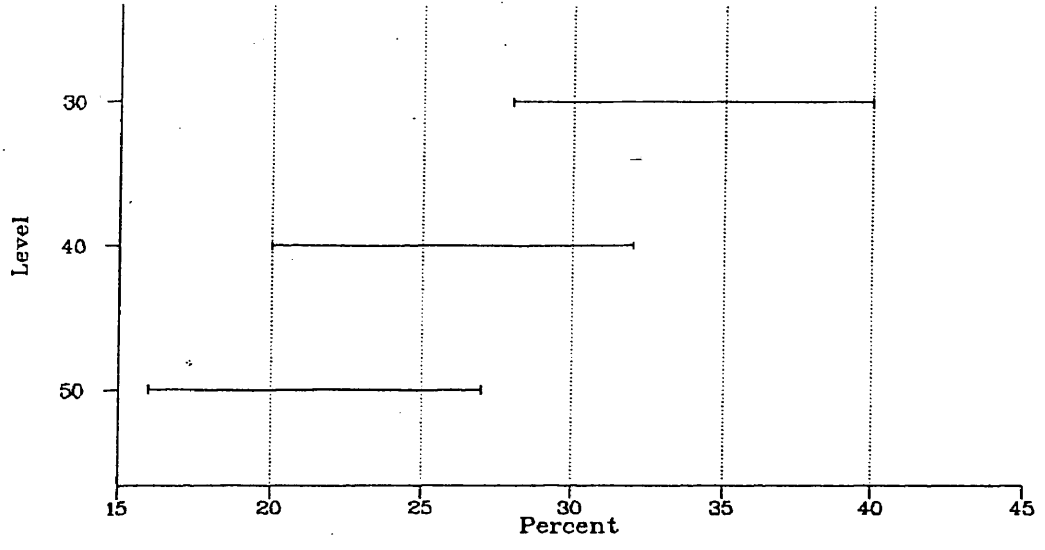

Text-Figure 52. 95% confidence intervals for running averages of Cupuliferoipollenites percentages, C seam of Sequence E.



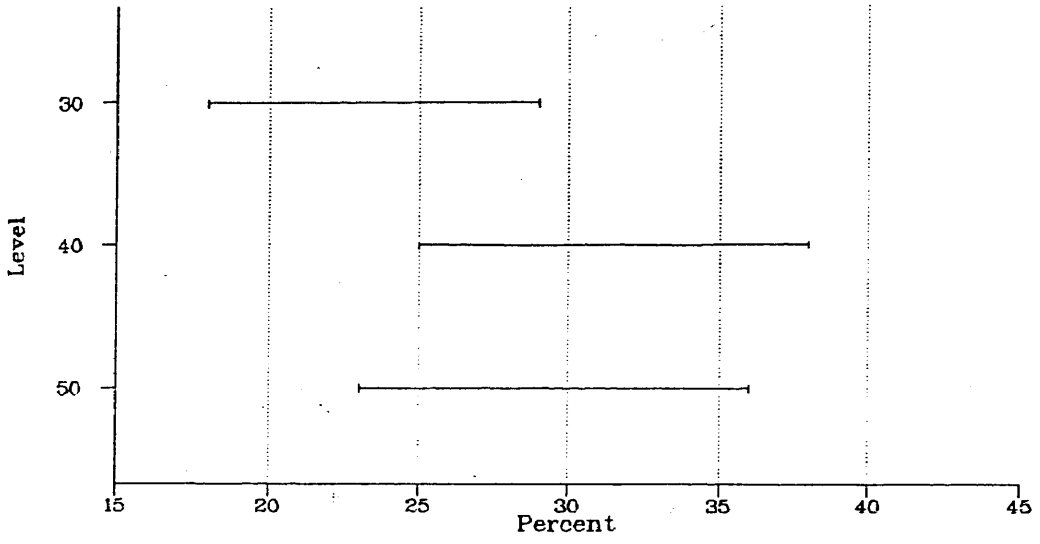

Text-Figure 53. 95% confidence intervals for running averages of Momipites coryloides percentages, C seam of Sequence E.



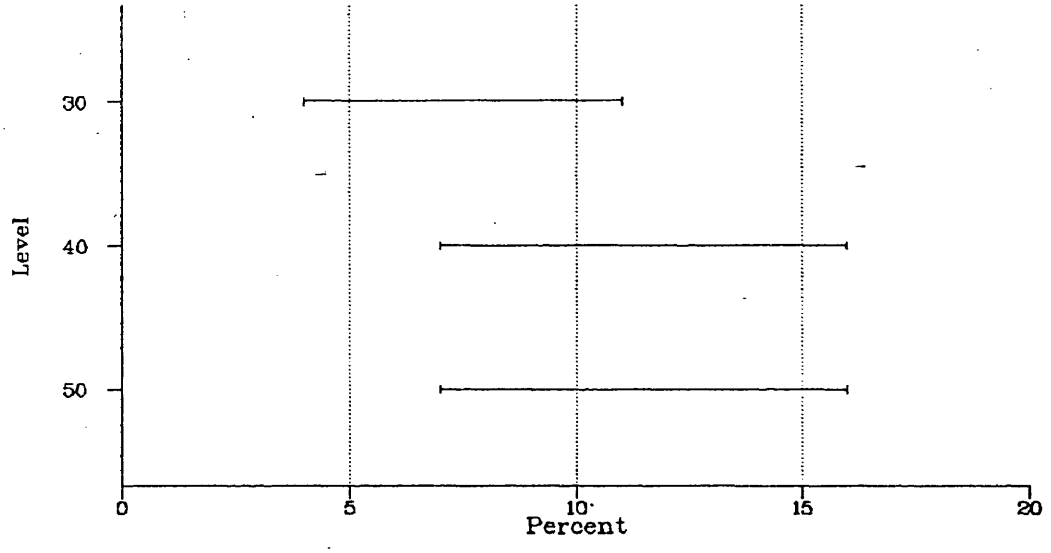

Text-Figure 54. 95% confidence intervals for running averages of Rhoipites angustus percentages, C seam of Sequence E.



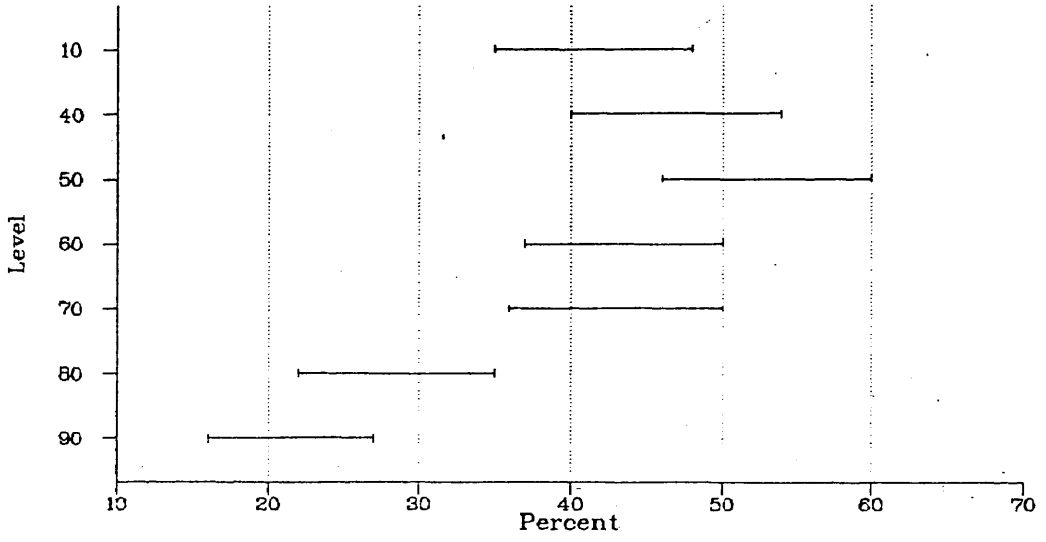

Text-Figure 55. 95% confidence intervals for running averages of Cupuliferoipollenites percentages, C seam of Sequence F.



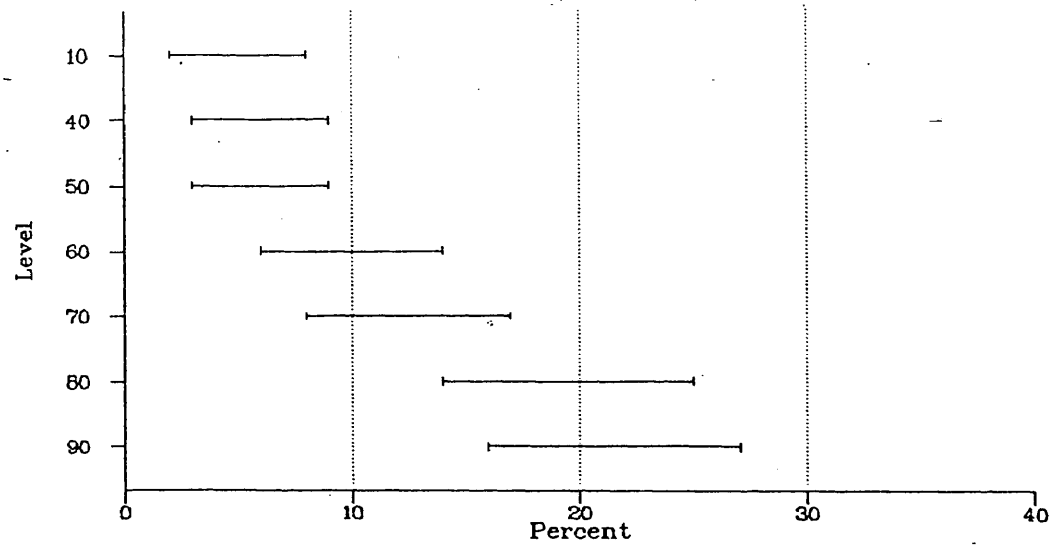

Text-Figure 56. 95% confidence intervals for running averages of Momipites coryloides percentages, C seam of Sequence F.



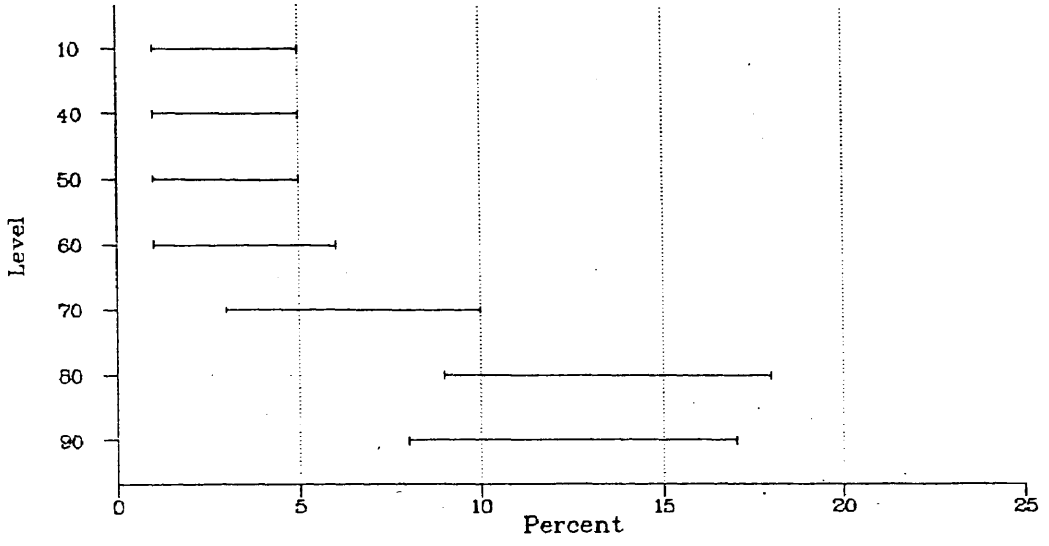

Text-Figure 57. 95% confidence intervals for running averages of Rhoipites angustus percentages, C seam of Sequence F.



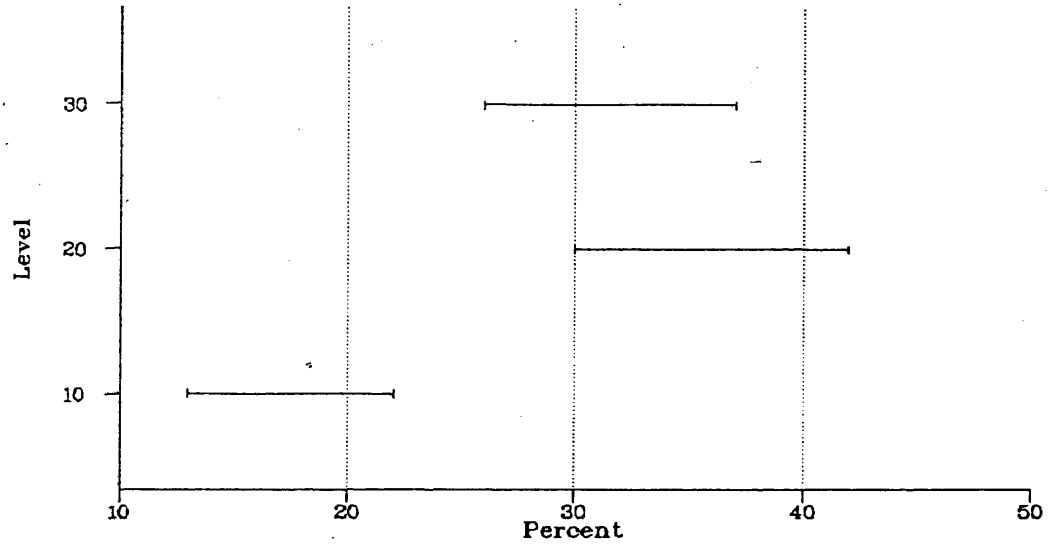

Text-Figure 58. 95% confidence intervals for running averages of Cupuliferoipollenites percentages, C seam of Sequence G.



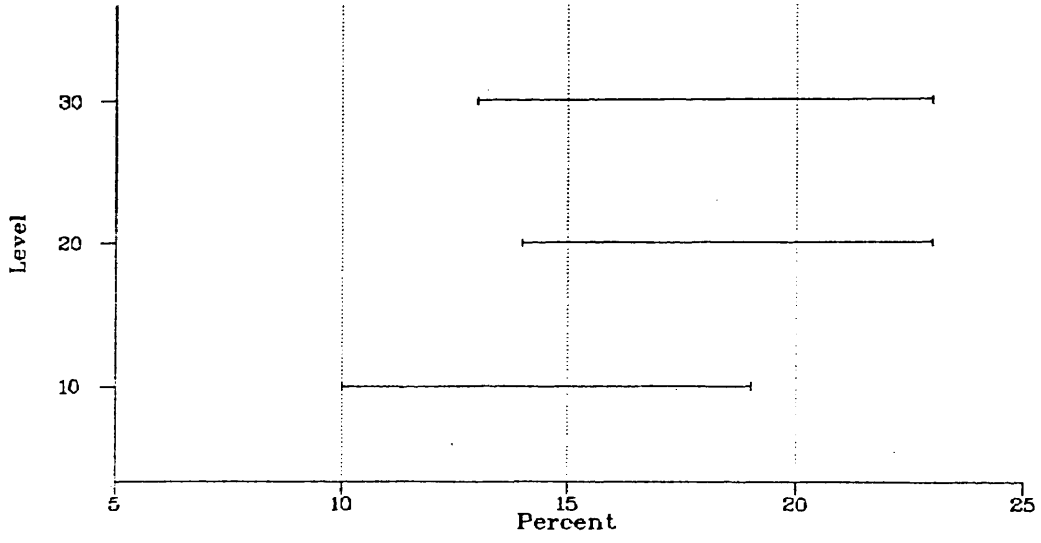

Text-Figure 59. 95% confidence intervals for running averages of Momipites coryloides percentages, C seam of Sequence G.



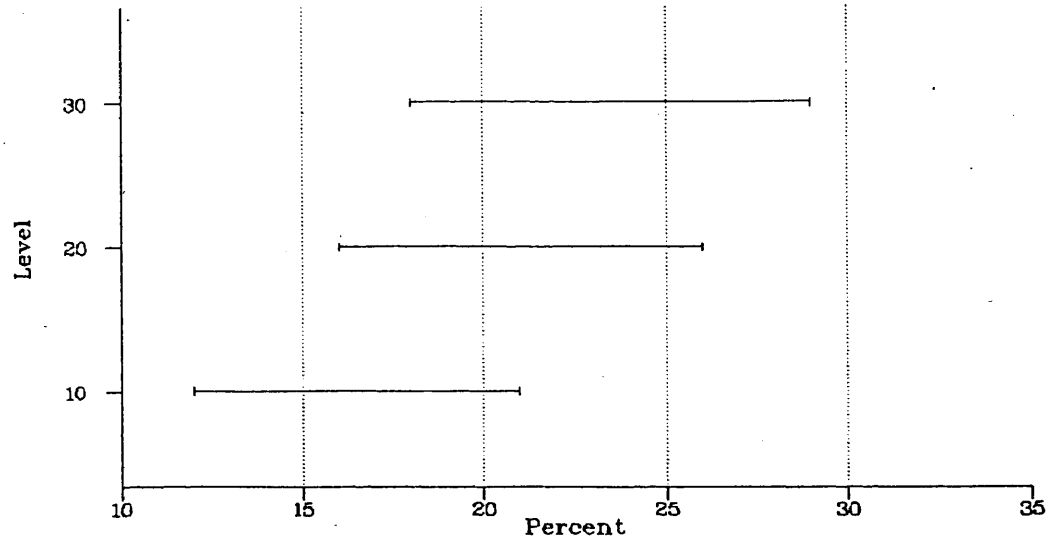

Text-Figure 60. 95% confidence intervals for running averages of Rhoipites angustus percentages, C seam of Sequence G.




Text-Figure 61. 95% confidence intervals for running averages of Cupuliferoipollenites percentages, C seam of Sequence H.




Text-Figure 62. 95% confidence intervals for running averages of Momipites coryloides percentages, C seam of Sequence H.




Text-Figure 63. 95% confidence intervals for running averages of Rhoipites angustus percentages, C seam of Sequence H.

Cupuliferoipollenites. In graphs from each of the seams analyzed for variability, at least two samples exist for which the confidence intervals of Cupuliferoipollenites do not coincide. This means that all values of Cupuliferoipollenites cannot be considered statistically identical throughout any vertical sequence through any seam examined palynologically at San Miguel. In three of the C seam sequences and five of the D seam sequences averaged Momipites coryloides percentages are not statistically identical at all levels. Conversely, in five sequences from the C seam and one sequence from the D Seam, all M. coryloides values are statistically the same. Likewise, averaged Rhoipites angustus percentages are not all statistically identical in five of eight C seam sequences and in five out of six D seam levels.

For these two taxa, the more complete sequences with their greater number of samples are more variable and confidence intervals are less likely to overlap in all samples. The relatively complete C seam of sequence D, in which all Rhoipites angustus averages can be considered statistically the same, has a very low percentage of that taxon at all levels, and no R. angustus peak at the base. Instead, there is a Momipites coryloides peak; this is one of the few C seam sequences in which M. coryloides variation is statistically significant using this method.

**Discussion.** The confidence interval analysis of running averages underlines the extreme variability of palynological samples, and the need to consider confidence intervals in assessing trends within a vertical sequence. Assuming that the variability revealed in the closely-spaced horizontal samples reflects the effects of sampling rather than a vegetational gradient, the variability of vertical

sequences must be evaluated against this standard. These results do suggest that some groups of samples and taxa are more variable than others: the vertical overburden sequences are less variable than either the horizontal or vertical lignite sequences and the vertical lignite sequences are the most variable of all three sequence types, supporting the interpretation of a replacement of lignite-forming communities through time.

The palynological input into the overburden was largely regional, whereas the input into the lignite samples contained more palynomorphs with a local origin (Darrell, 1973). This contrast in variability between the clastic overburden samples suggests that palynomorphs deposited in water are more thoroughly mixed before deposition than palynomorphs deposited in peats. Jones and Gennett (1991) presented a clastic palynomorph flora from the Claiborne Group which, like the overburden sequence, exhibited very few substantial changes throughout the extent of the formation. The palynological uniformity of these two Eocene clastic sequences suggests that no significant climatic changes took place during their depositions. It is, consequently, easy to rationalize a regionally derived palynoflora with no statistically significant changes throughout a hundred or so meters of overburden.

The statistically significant changes in the three taxa which occur in the lignite are probably "real" and were caused by changes in the lignite flora, and not by regional floral variations. Because the percentages of all taxa are affected by the influx of all other pollen taxa, and because it is impossible to measure palynomorph influx without dating the lignites, it is difficult to determine what proportion of each palynomorph taxon is local. It should, however, be

reasonable to assume that the statistically significant changes in the vertical sequences are representative of actual changes which occurred in the local vegetation.

Diversity

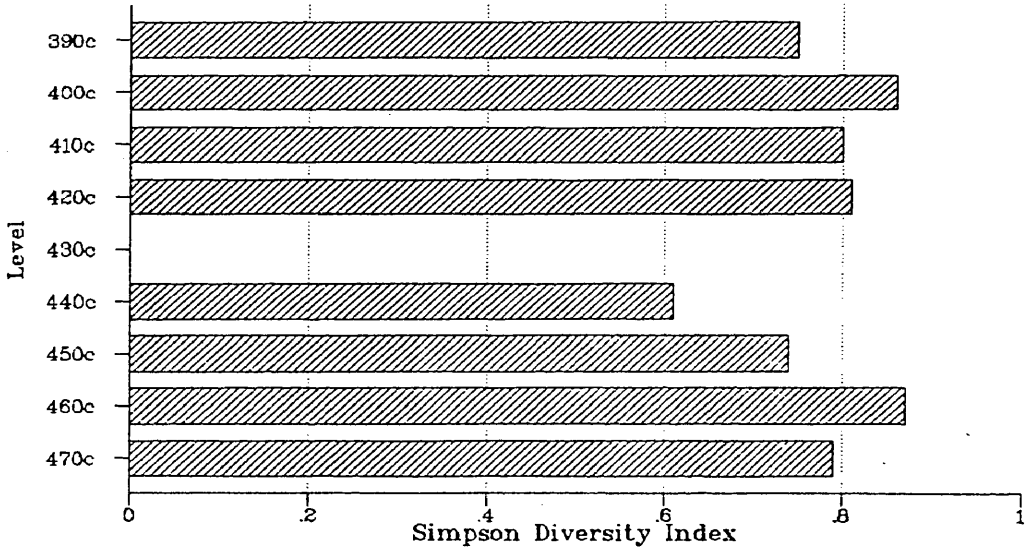
**Introduction.** Nichols and Traverse (1971) indicated that the number of palynomorph taxa present in a given sample, represented by the Simpson Diversity Index, may differ with depositional environment. Simpson diversity measures both the number of taxa in a sample (richness) and the relative abundance of these taxa. The index "...expresses the probability that two specimens taken at random belong to the same species." (Margalef, 1978, p. 252.) It has the disadvantage of deleting taxa which have a single occurrence a given sample (Nichols and Traverse, 1971).

The formula for the Simpson Diversity Index is:

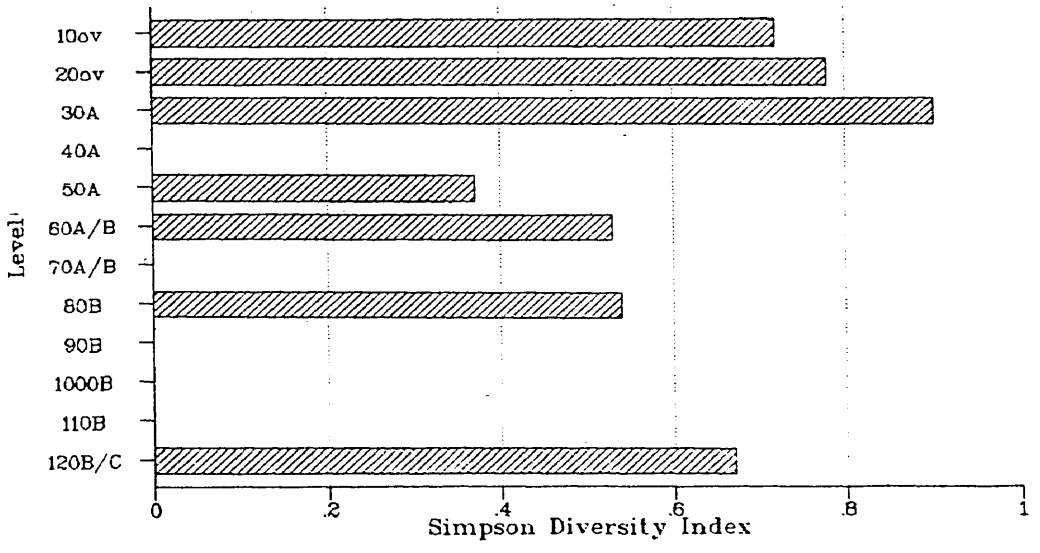
$$B = \sum_{i=1}^{s} \frac{N_i(N_i-1)}{N(N-1)}$$

where $N_i$ is the number of individuals in species i, N is the total number of individuals in the sample, and s is the number of species (Margalef, 1978).

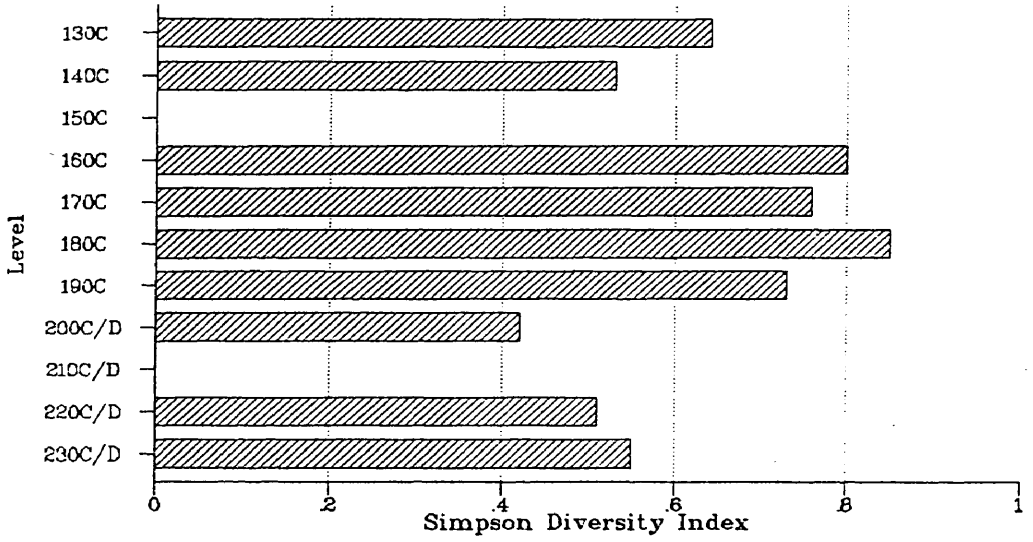
**Methods and Results.** I calculated Simpson Diversity Indices for each sequence from the San Miguel lignites, as well as for Lake Somerville, with the MVSP program developed by Warren Kovach at the University College of Wales using the option which transformed the species data using log base 10, in order to emphasize rare taxa. These indices, plotted against depth, are shown in Text-Figures 64-82.



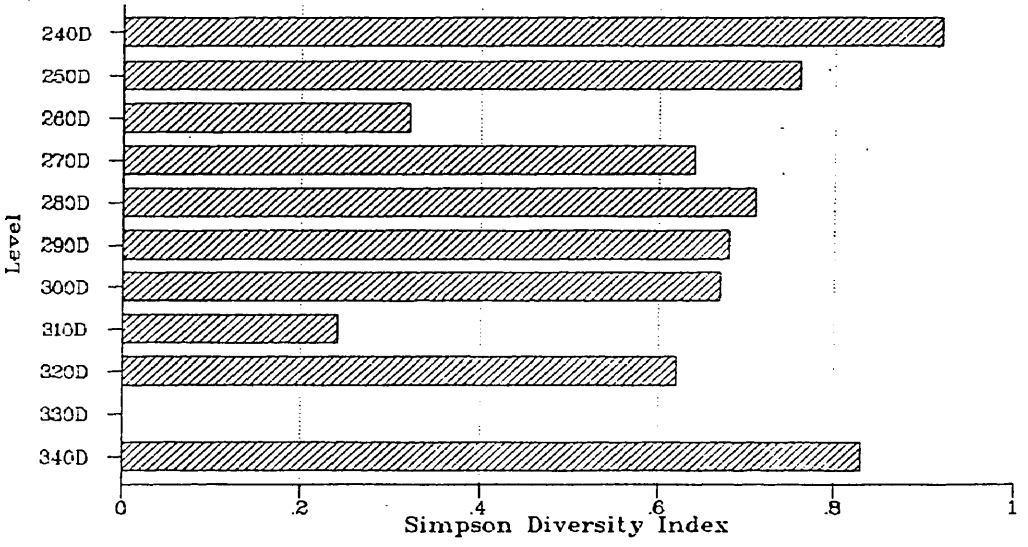

Text-Figure 64. Simpson diversities for Sequence A.



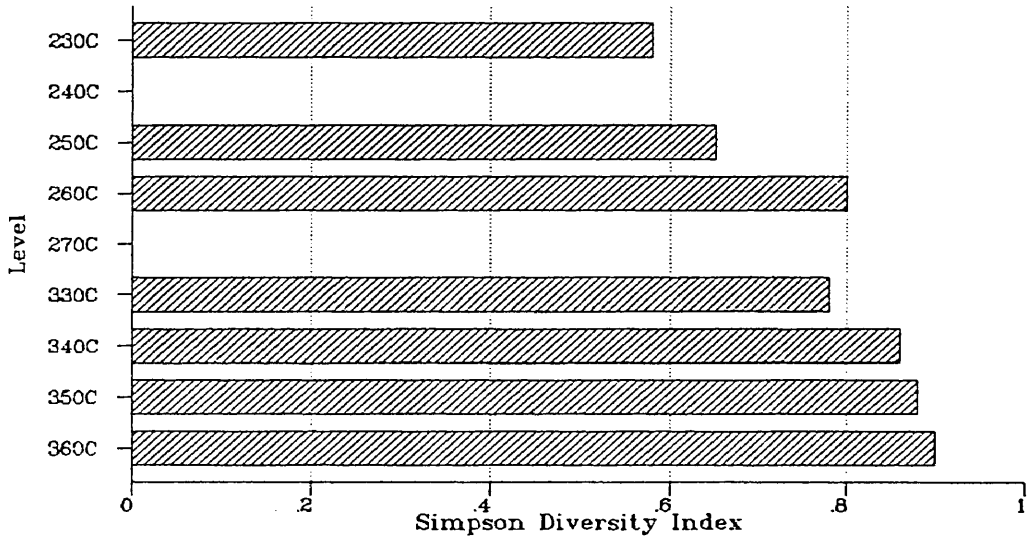

Text-Figure 65. Simpson diversities for Sequence B, A to B seams.



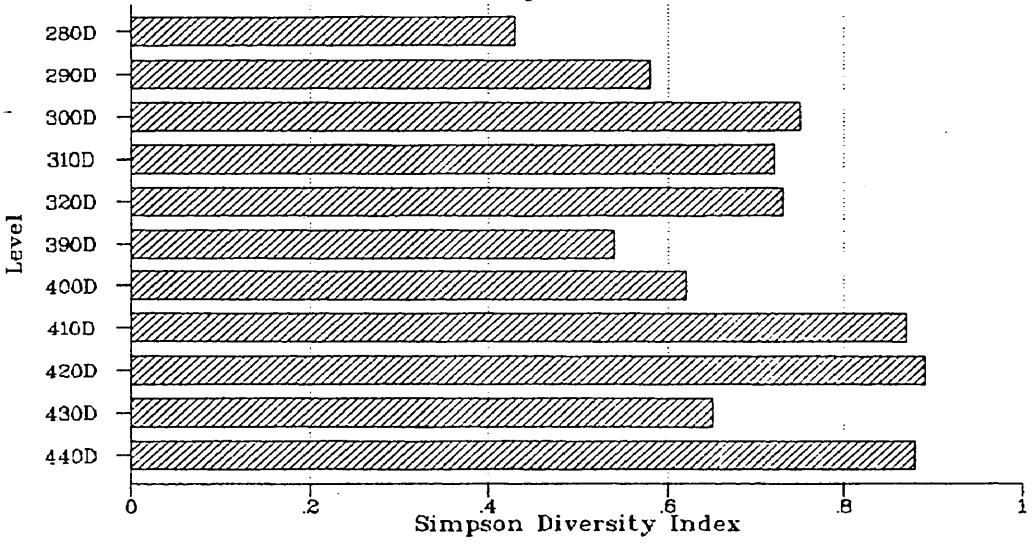

**Text-Figure 66. Simpson diversities for Sequence B, C seam.**



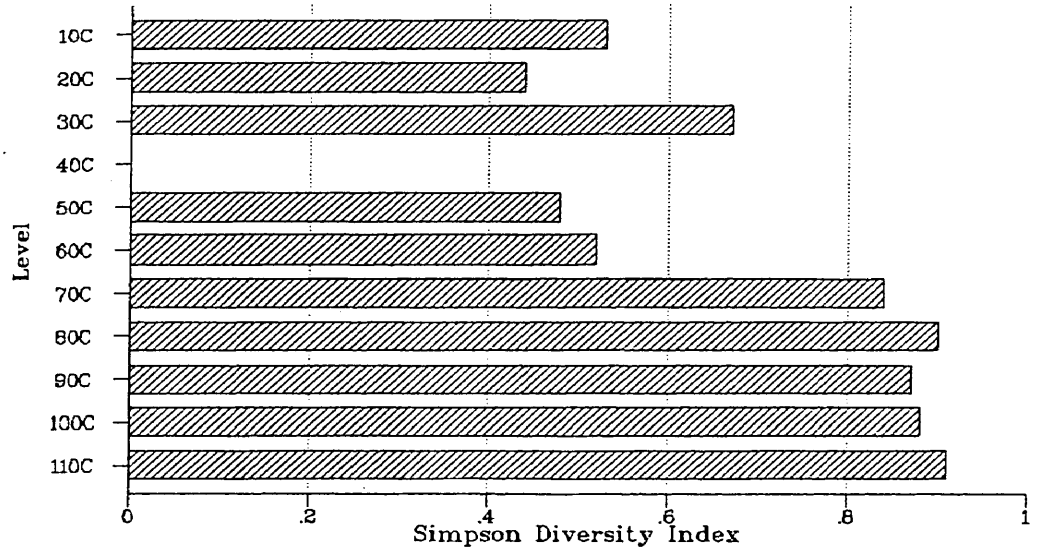

**Text-Figure 67. Simpson diversities for Sequence B, D seam.**



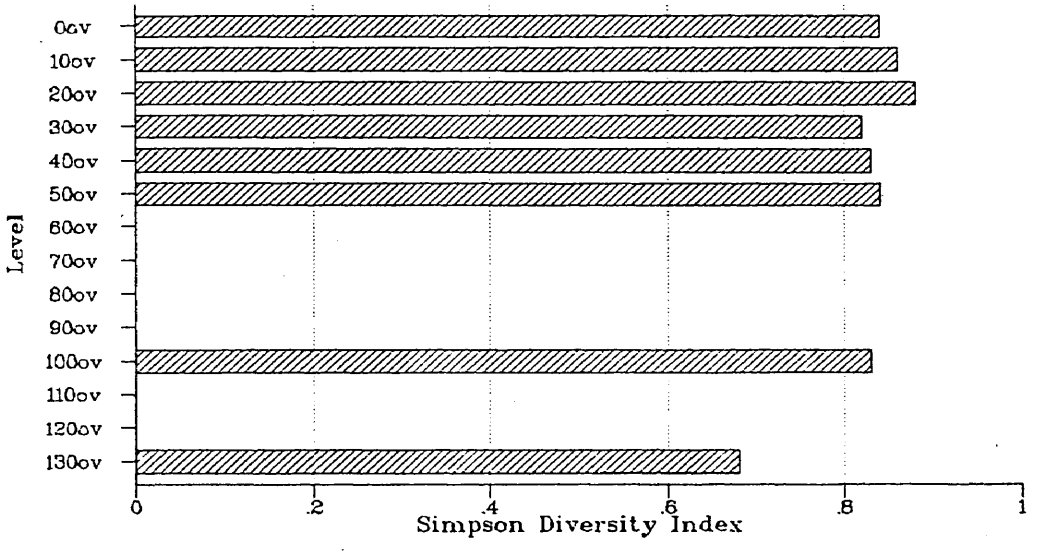

Text-Figure 68. Simpson diversities for Sequence C, C seam.



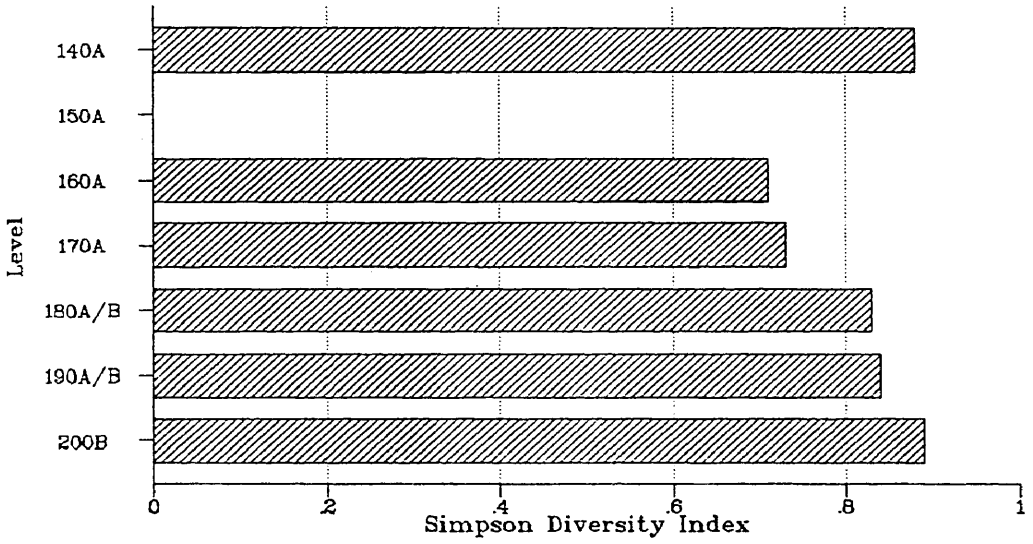

Text-Figure 69. Simpson diversities for Sequence C, D seam.



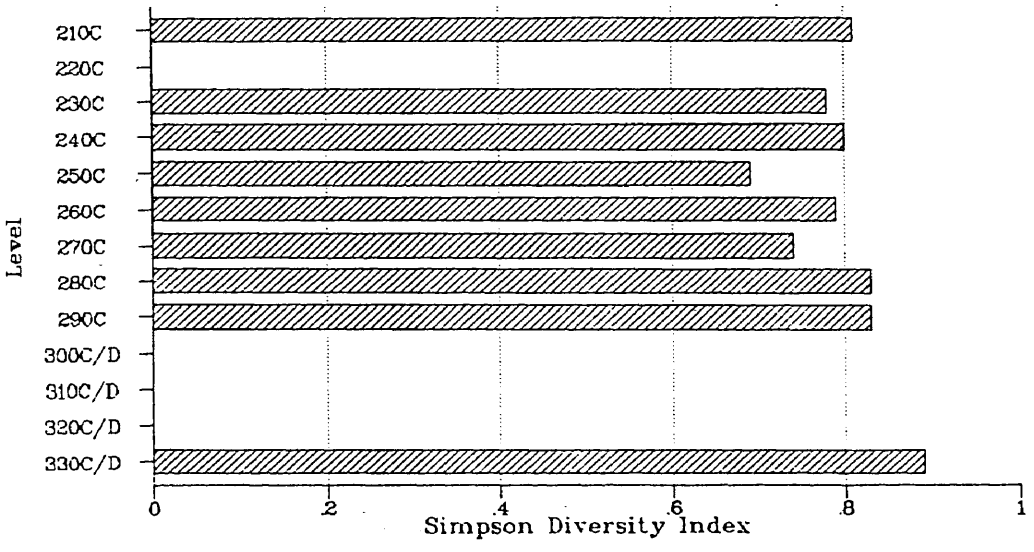

Text-Figure 70. Simpson diversities for Sequence D.



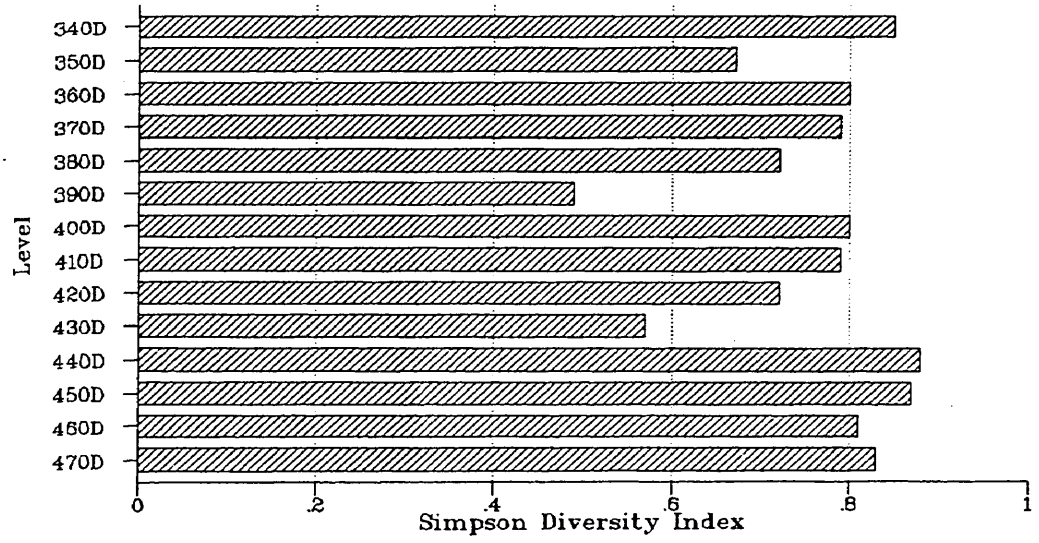

Text-Figure 71. Simpson diversities for Sequence E, overburden.



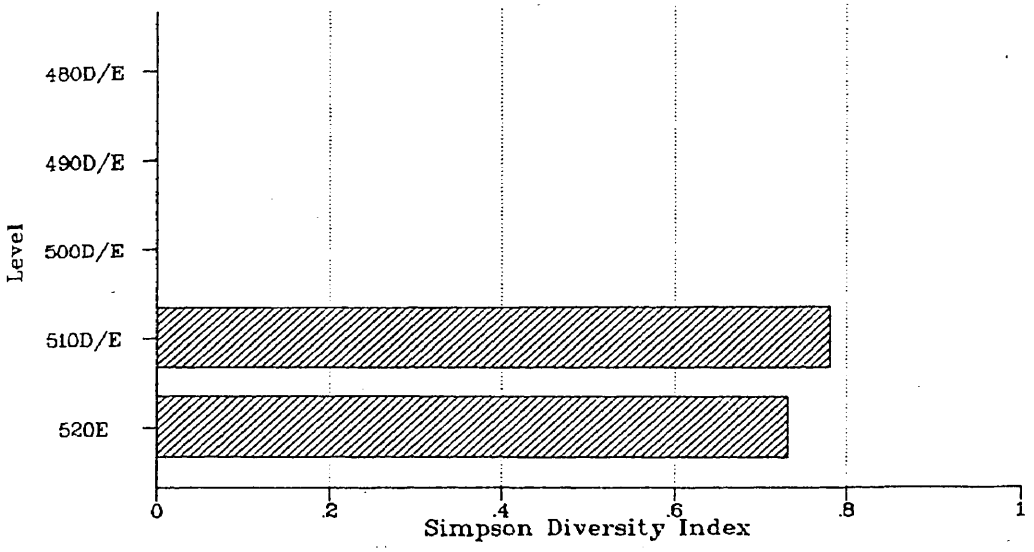

Text-Figure 72. Simpson diversities for Sequence E, seams A and B.



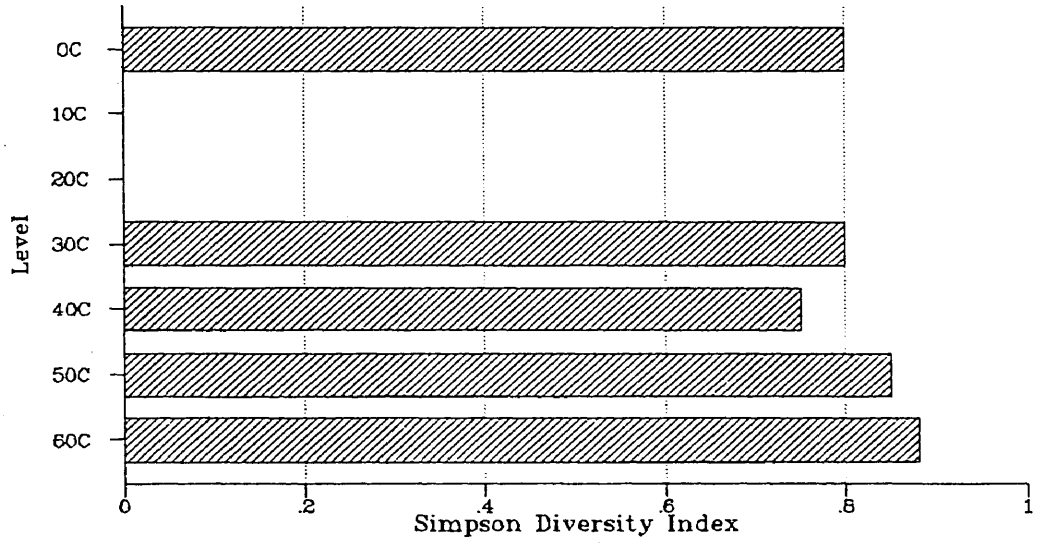

Text-figure 73. Simpson diversities for Sequence E, C seam.



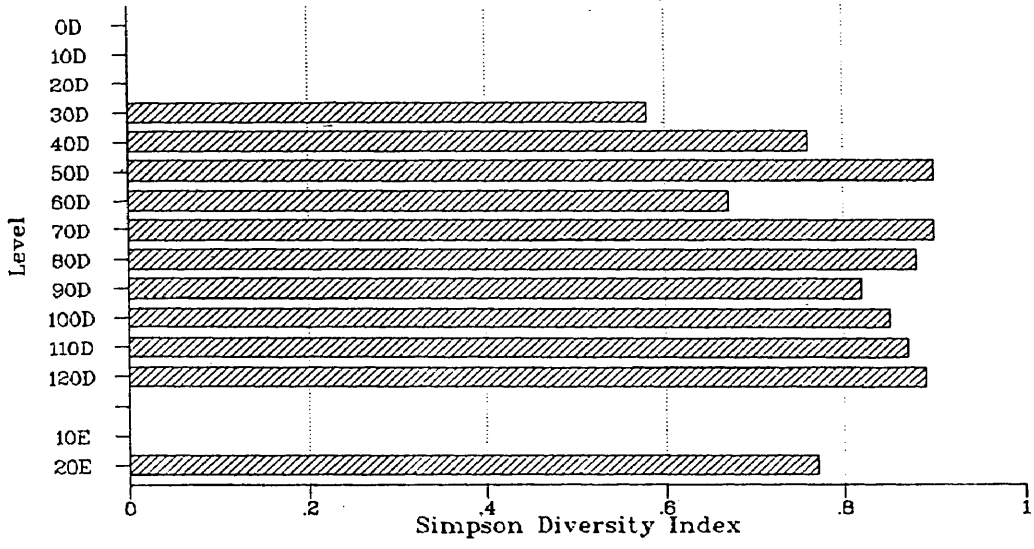

Text-Figure 74. Simpson diversities for Sequence E, D seam.



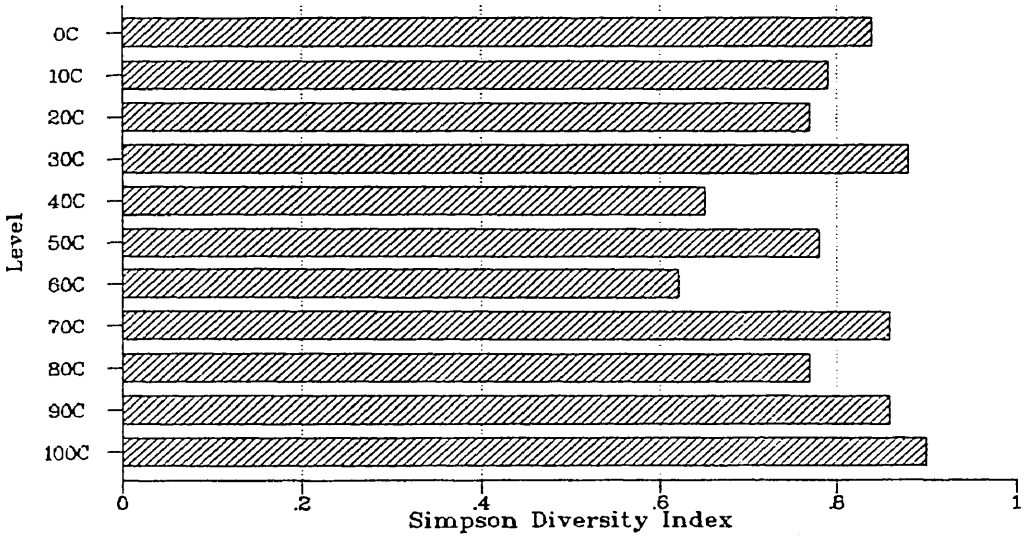

Text-Figure 75. Simpson diversities for Sequence E, E seam.



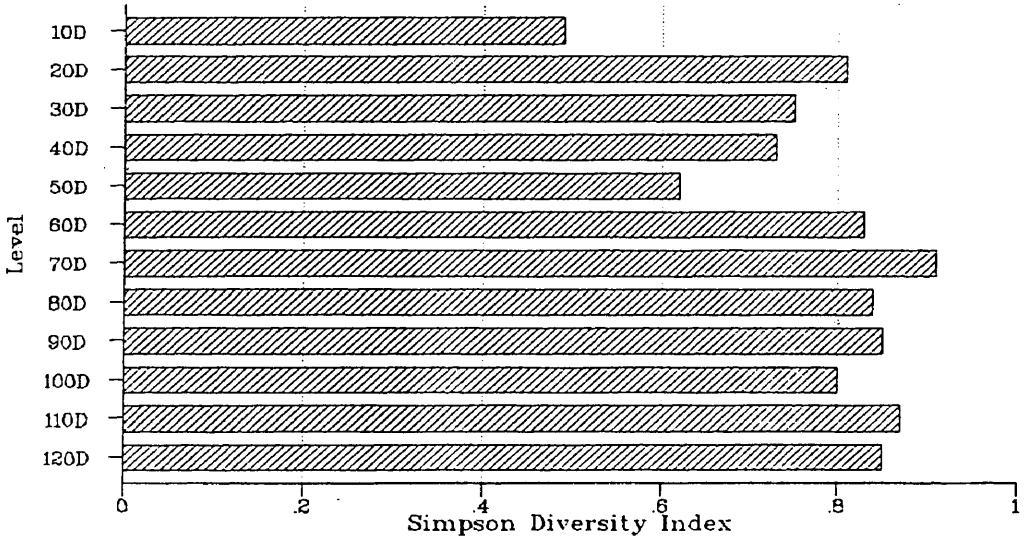

Text-Figure 76. Simpson diversities for Sequence F, C seam.



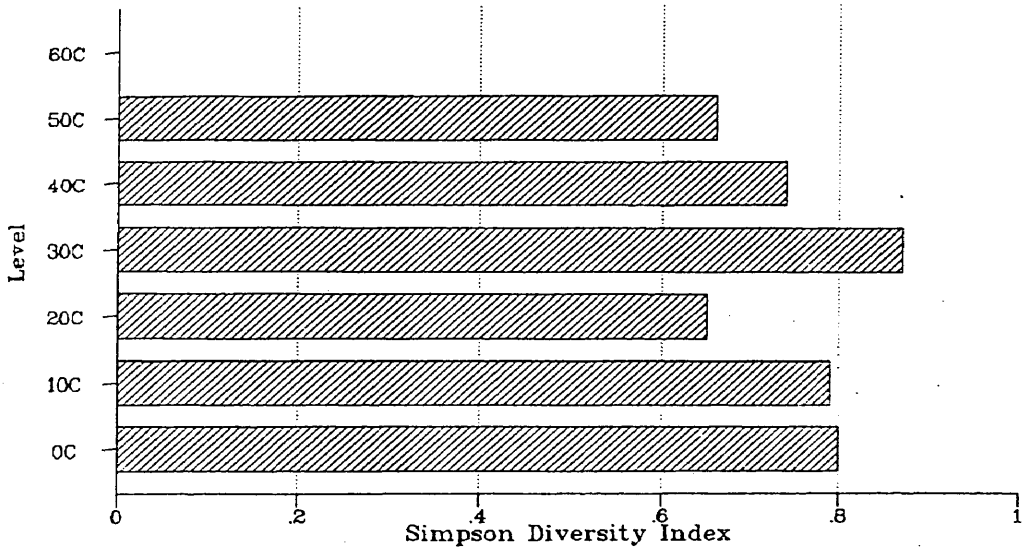

Text-Figure 77. Simpson diversities for Sequence F, D to E seam.



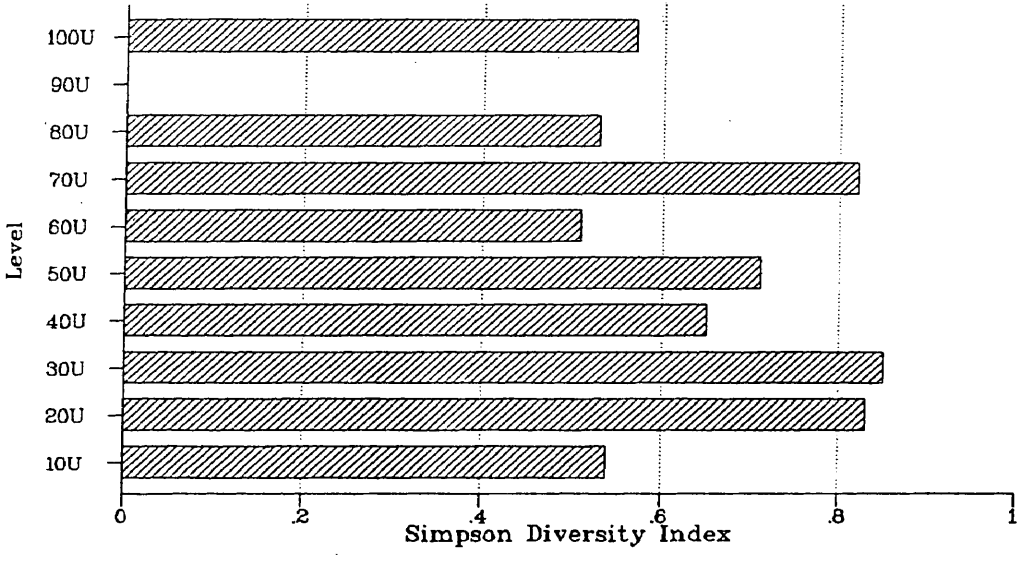

Text-Figure 78. Simpson diversities for Sequence G, C seam.



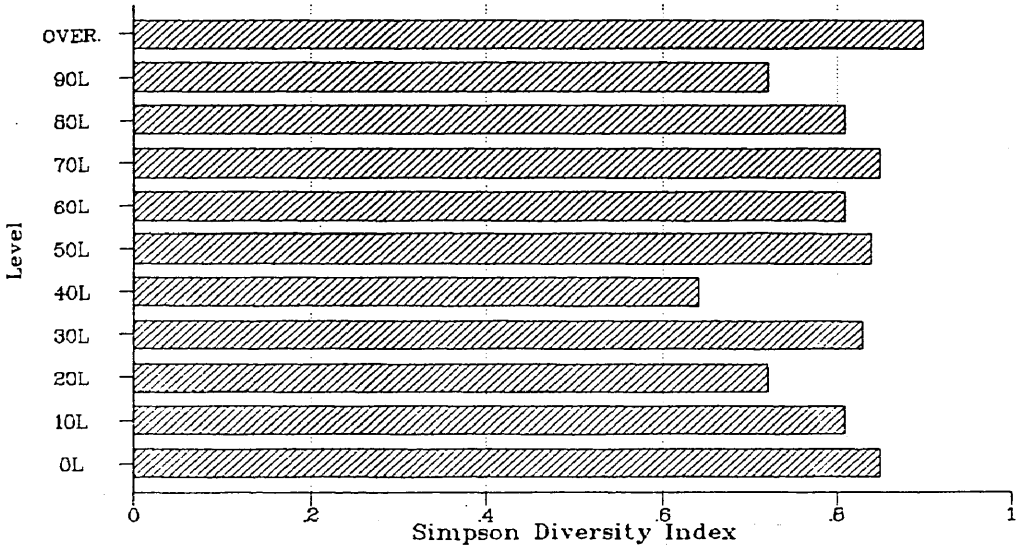

Text-Figure 79. Simpson diversities for Sequence G, D seam.




Text-Figure 80. Simpson diversities for Sequence H.




Text-Figure 81. Simpson diversities for Lake Somerville, upper seam.

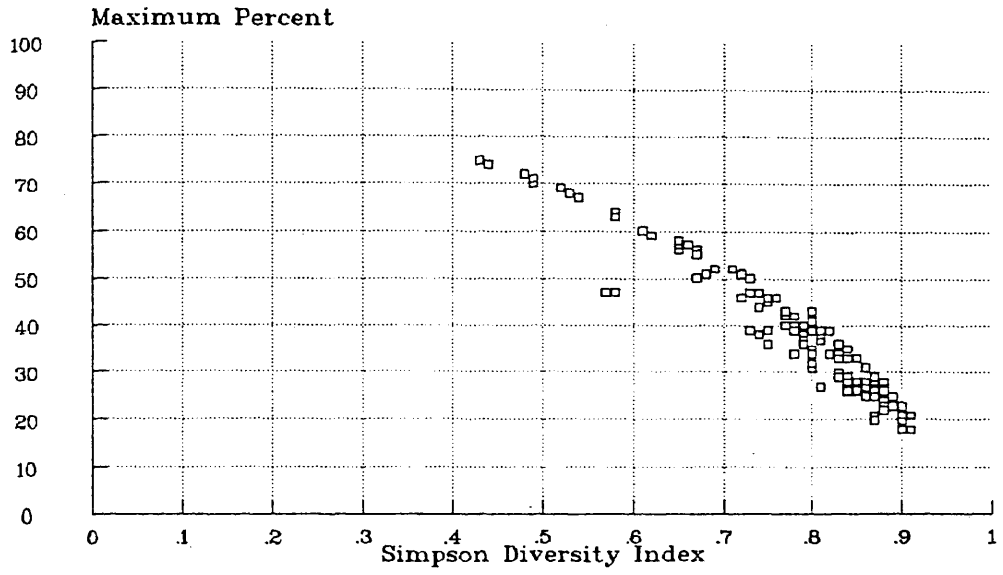



Text-Figure 82. Simpson diversities for Lake Somerville, lower seam.

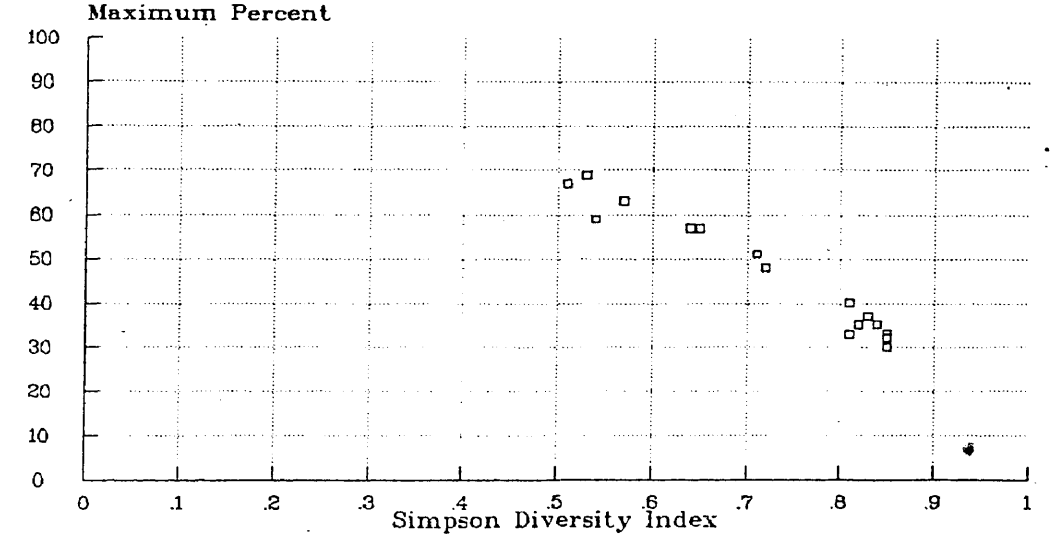
In Sequences B, C and D, diversity decreases conspicuously in the top half of the C Seam. In other sequences, this decrease is not as clear, but, in all sequences, low diversities in the seam correlate with high Cupuliferoipollenites percentages. Plots from the D seam show several diversity dips, which correspond to high values of dominant taxa, including Cupuliferoipollenites.

Text-Figures 83 and 84 show the relationship between the maximum palynomorph percentage per level and Simpson diversity in the San Miguel sequences and at Lake Somerville. Sequence B is omitted because the castolite mounting medium may have affected pollen identification, and because small tricolporates were lumped together for counting in some levels. Regression analysis shows an adjusted coefficient of determination ($r^2$) of .92 for the San Miguel samples and .96 for Lake Somerville samples. This indicates that over 90% of the variation in the diversity index is explained by variation in maximum palynomorph percentage. and suggests that these variables are closely related.

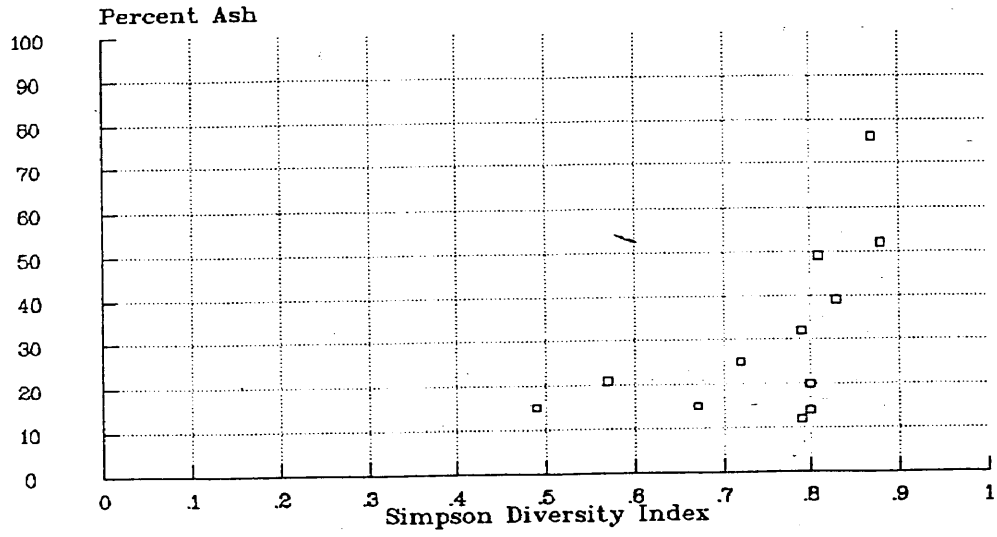
I have also compared diversity to ash and sulfur data where it is available. The San Miguel and Lake Somerville lignites show a different relationship between palynomorph diversity and percent ash (Text-Figures 85 and 86). In the Lake Somerville samples (Text-Figure 86), diversity is weakly dependent ($r^2$=.43) on ash content. It is clear, however, from the graphs that the two samples with high percentages (over 50%) of ash have relatively low diversities. Samples with less than 50% ash content have both relatively high and low diversities. The regression line relating ash percentage and diversity in the San Miguel samples (Text-Figure 85) has an $r^2$ of .13. This low figure



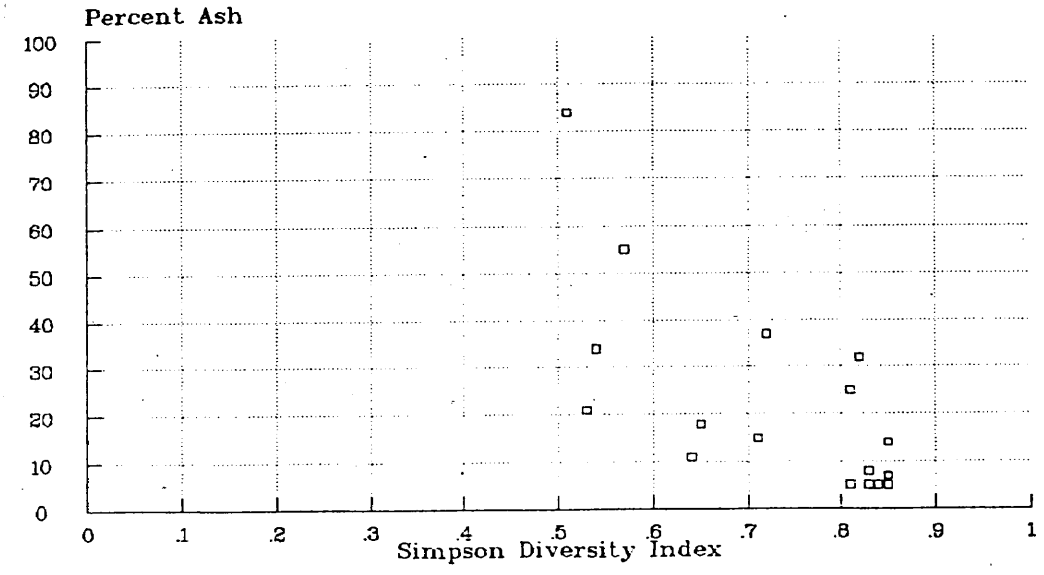

Text-Figure 83. Simpson diversity vs. maximum palynomorph percent in the San Miguel lignites.




Text-Figure 84. Simpson diversity vs. maximum palynomorph percent in the Lake Somerville lignites.




Text-Figure 85. Ash vs. Simpson diversity in Sequence E of the San Miguel lignites.



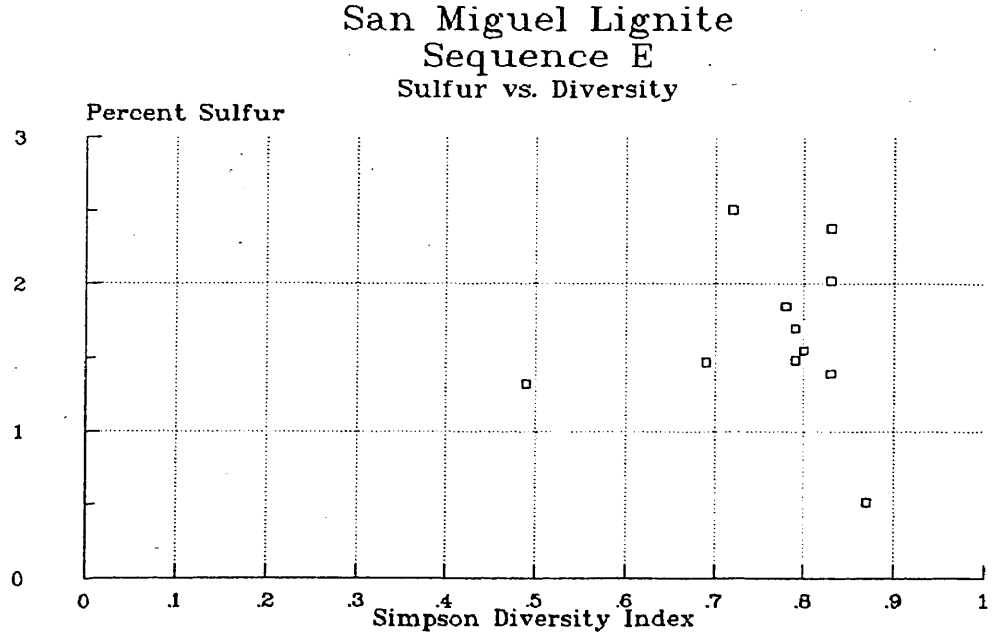

Text-Figure 86. Ash vs. Simpson diversity in the Lake Somerville lignites.

indicates that there is very little dependency between these variables, but regression is not always the best method of defining ecological relationships (Gauch, 1982). In the San Miguel samples, levels with relatively high (>30%) ash percentages have uniformly high content diversities, whereas diversities in samples with low (<30%) ash percentages are both high and low. These disparities may reflect different sources for the ash in the lignites; a high ash from a clastic source would introduce a greater variety of palynomorphs than a high ash contact from a volcanic source. This would imply that the source of ash in the San Miguel lignites was largely clastic. Unfortunately, there is insufficient data on which to base this conclusion.

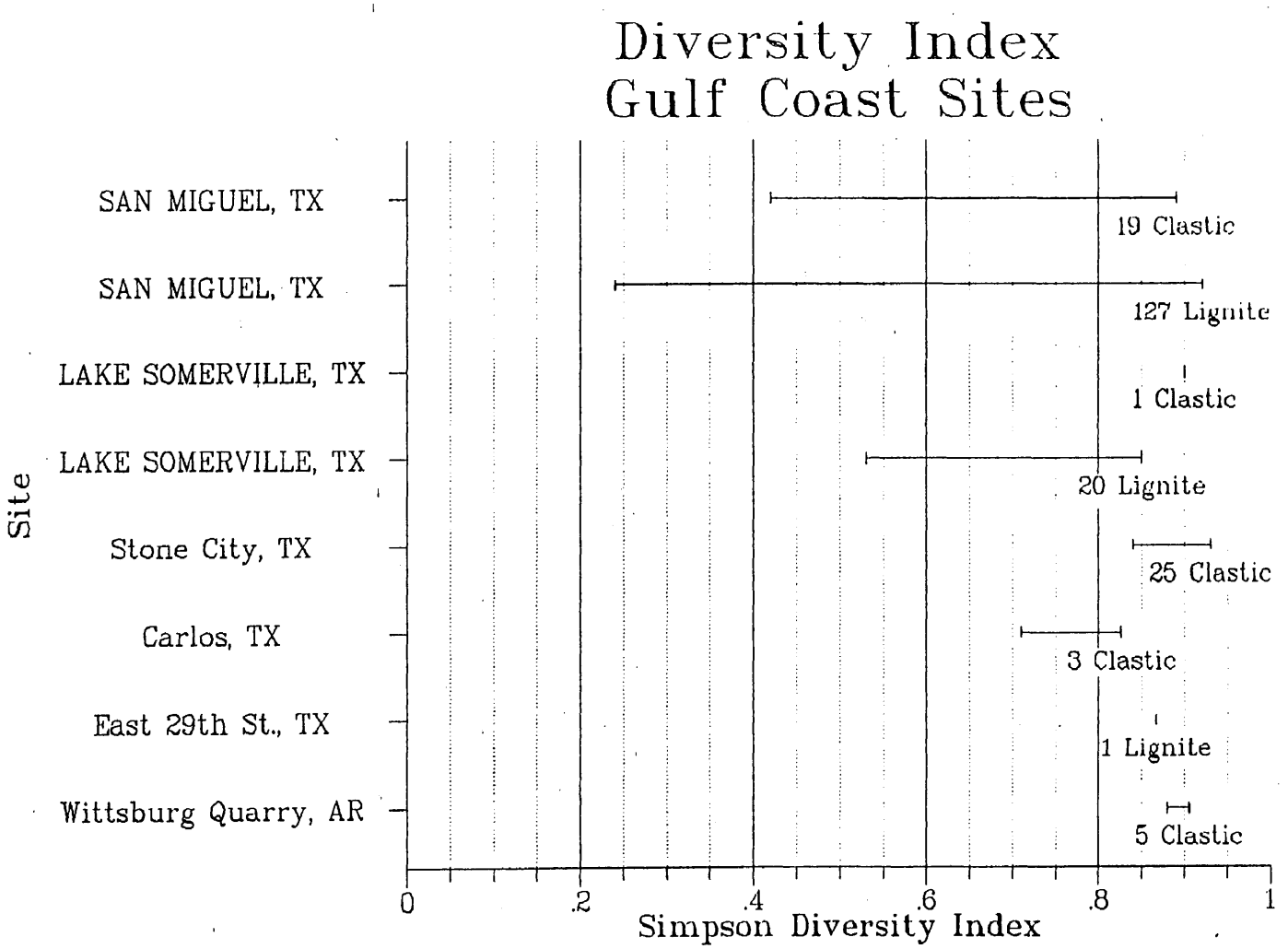
The plot of sulfur percentage against diversity for Sequence E of the San Miguel lignite (Text-Figure 87) suggests that there is little or no relationship between these two variables, yielding a "statistically insignificant" $r^2$ of .2. In this sequence, samples with low total sulfur have relatively high diversities; samples with sulfur values of >2% have either high or low diversities. In the sulfur vs. diversity plot for Sequence E, the $r^2$ is again statistically insignificant at -.12. The only low diversity values occur in the interval between 1.5 and 2.5 % sulfur. In the sulfur vs. diversity plot for Sequence E, the $r^2$ is also statistically insignificant at -.14, and no segregation of low and high values is visible.

Text-Figure 88 shows palynomorph diversities from other Gulf Coast Eocene sites. In each case, many fewer samples were analyzed than at San Miguel. Samples from the marine Middle Eocene Stone City Formation (Jones and Gennett, 1991) yield uniformly high diversities, as do clastics from the Middle Eocene (?) section at Wittsburg

Quarry in Arkansas (Gennett, 1990). These clastic sites also have a comparatively low range of diversities. Upper Eocene lignite samples from the Gibbons Creek Mine (Gennett et al., 1986) have lower and more variable diversities than the clastics. The one Yegua (Uppermost Middle Eocene) lignite sample, mentioned in this study,




Text-Figure 87. Sulfur vs. Simpson diversity in Sequence E of the San Miguel lignites.




Text-Figure 88. Simpson diversities of samples from some Eocene Gulf Coast Sites

has a diversity within the range of the clastic samples from San Miguel.

The clastic overburden samples from Sequence E of the San Miguel lignites have an average diversity of .822; if the lowermost sample at 130 cm, which is adjacent to the A seam, is removed from consideration, the average diversity is .843. The average diversity for four parting samples is .835. These averages are lower those than the .898 value for estuarine samples from Wittsburg Quarry. The San Miguel clastic averages are also lower than the .892 average from the marginal marine Stone City Fm.

The average diversity of all samples from Lake Somerville is .740; the average for C seam lignites from San Miguel is .769; and for D seam lignites from San Miguel, the average is .748. These average diversities are lower than those of these clastics from San Miguel, although the diversities for some lignite samples are as high as for the clastic samples.

Diversity indices, although commonly used by paleozoologists, have not been regularly employed by palynologists. Birks and Gordon's (1985) text on the use of statistics in Quaternary pollen analysis makes no mention of diversity indices. Some qualitative information on diversity is available for modern environments. Darrell (1973) pointed out that there were "more morphotypes" deposited in the bay sedimentary environments of the Mississippi Delta than in the marsh environments. Both environments have "fewer morphotypes with more individuals per morphotype" than channel, levee, distributary mouth bar, delta front, and prodelta environments. I computed the Simpson diversity for the uppermost, probably modern, sample from a peat in a small pond in Wyoming (Gennett, 1977) surrounded by

douglas fir steppe to be only .07, with only 7 taxa. Jacobs (1982), counting at least 200 grains per sample, found as few as 8 taxa in soil samples from pine forest and as many as 20 taxa in mangrove swamp in Northern Mexico.

Biological diversity is dependent on numerous factors such as environmental stability and resource availability (Dodd and Stanton, 1981). Additionally, transport has a substantial effect on fossil palynomorph diversity because pollen and spores act as silt size particles. By consequence, diversity for a given site may be further determined during the depositional process by the relative input from the various transport agents: wind, water, and gravity. A sedimentary site receiving clastic input from a large river would theoretically have a higher diversity than one with no stream input. A large, open site such as a marsh, receiving input both from the local marsh communities and from the forests in the region, would have a higher diversity palynomorph assemblage than a small pool within a closed forest (Moore and Webb, 1978).

Because numerical diversity has not been well studied for palynomorphs, it is difficult to make significant conclusions from the figures given here. However, within the samples for which data are available, ash and sulfur have little influence on diversity. A high ash content due to clastic influx from fluvial systems would hypothetically imply a higher diversity of fluvially transported palynomorphs. This is not the case at either San Miguel or Lake Somerville, and this fact suggests that volcanic ash may comprise at least some of the ash in the lignites.

Palynomorph Concentration

**Introduction.** Palynomorph concentration is often used by Quaternary palynologists to estimate the actual number of palynomorphs present in a given amount of sediment. If the sedimentation rate is constant or if the sequence is well-dated, palynomorph concentration provides palynomorph spectra in which the quantity of each taxon is calculated independently in relation to other taxa. If preservation is good, each spectrum in an approximation of palynomorph input at the sample site at the time of deposition.

Concentration is rarely used by Pre-Quaternary palynologists because it is cumbersome (Frederiksen, 1985; Farley and Traverse, 1990) and difficult to interpret. To compare concentration spectra, it is necessary to know, at least in relative terms, how much time was necessary to accumulate the sediment in each sample. Time references are rare in Pre-Quaternary palynomorph sequences, and deposition rates commonly vary even when sediment type does not (Moore and Webb, 1978). In fact, a recent paper by Farley and Traverse (1990) suggested that higher concentrations of specific taxa in different parts of a sediment sequence might be used to indicate clastic depositional environments.

**Methods and Results.** Palynomorph concentration was calculated using the formula given by Maher (1972):

$$C = \frac{11{,}300 \pm 400 \text{ Grains}}{\text{Lycopodium Grains Counted}} \times \frac{\text{Palynomorph Sum}}{\text{Volume of Sediment}}$$

C represents the palynomorph concentration. 11,300 ± 400 grains is the average number of grains in a Lycopodium tablet.

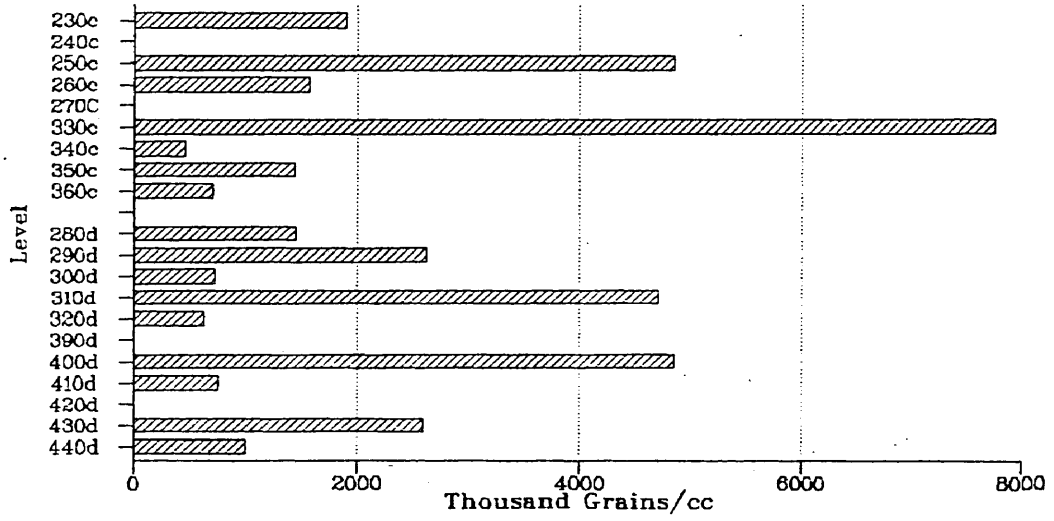
Palynomorph concentration for Cupuliferoipollenites, Momipites coryloides, Nyssa, and

Rhoipites angustus were then determined by substituting the taxon count for Palynomorph Sum in the formula.

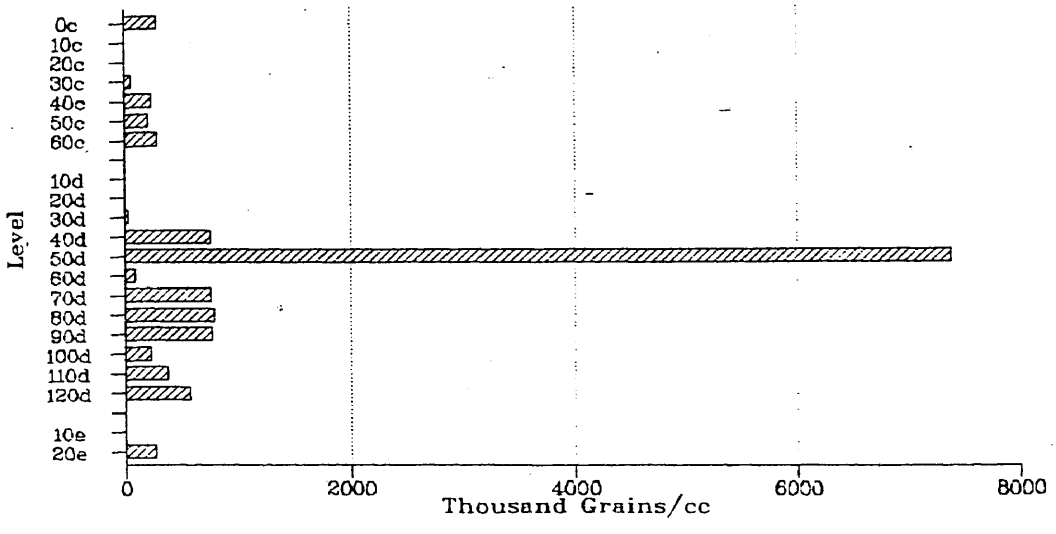
Histograms for Sequences C and F are shown in Text-Figures 89 and 90). Histograms were also constructed for four important taxa: Cupuliferoipollenites, Momipites coryloides, Nyssa, and Rhoipites angustus (Text-Figures 91-98). In both cores, total concentrations range up to 8,000,000 grains/cc, although, especially in the F sequence, many levels have total concentrations of less than 1,000,000. Concentration levels are variable. Except for higher concentrations in the upper part of the C seam of Sequence C, no pattern is apparent.

Cupuliferoipollenites concentrations are highest and most variable in both sequences, and values in general follow the pattern of total concentration. These concentration values are much higher (over 500,000 grains/cc) in the upper portion of the C seam of the C sequence than in the lower portion (less than 250,000 grains/cc); these concentrations correspond to percentages that rise to almost 65%. In the F sequence, Cupuliferoipollenites concentration values are less than 250,000 grains/cc throughout the seam, corresponding to maximum percentage values of around 40%. In the D seam, Cupuliferoipollenites concentrations are also tied to percentages. In the C sequence, maximum concentrations corresponding to higher percentages are much greater (over 500,000 grains/cc) than for the F sequence (less than 500,000 grains/cc except in one sample).

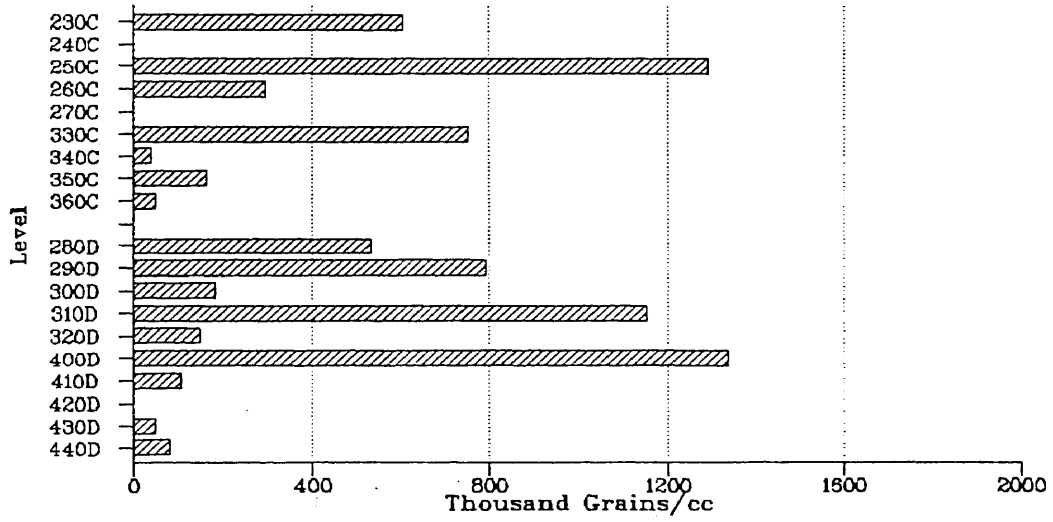
Momipites coryloides concentrations are on the average lower than Cupuliferoipollenites concentrations. M. coryloides concentrations are lower in the F sequence, which has higher M. coryloides percentages (to 55%) than the C sequence (to 20%).



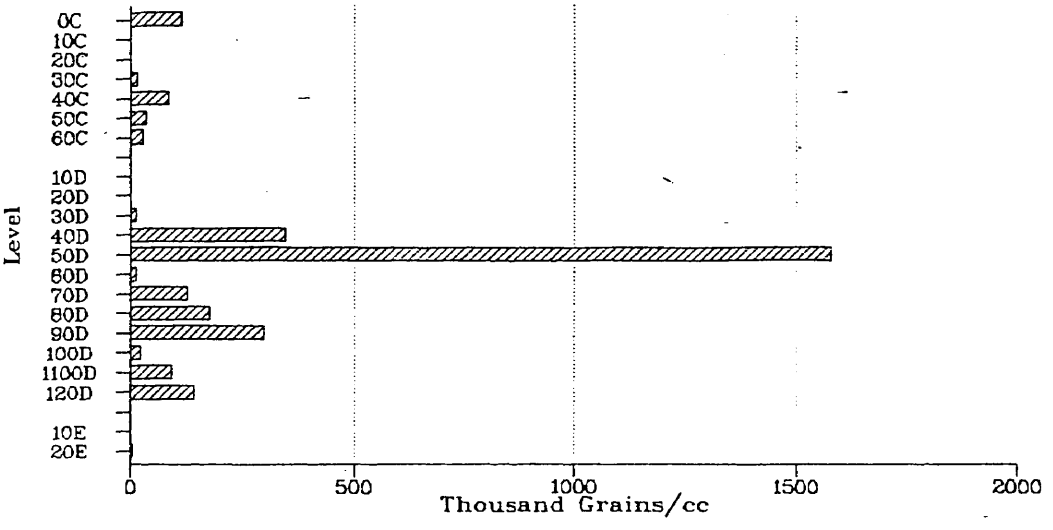

Text-Figure 89. Total palynomorph concentrations for Sequence C.



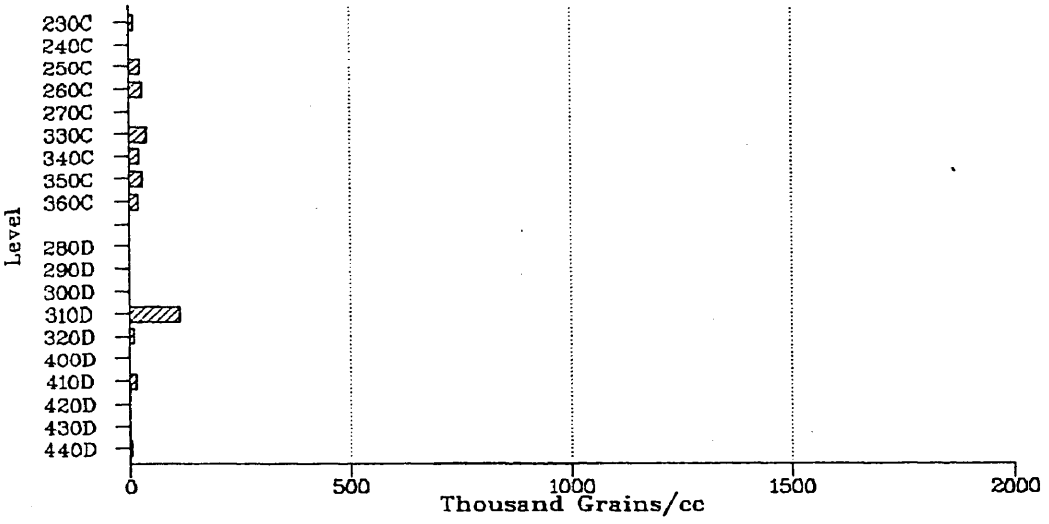

Text-Figure 90. Total palynomorph concentrations for Sequence F.



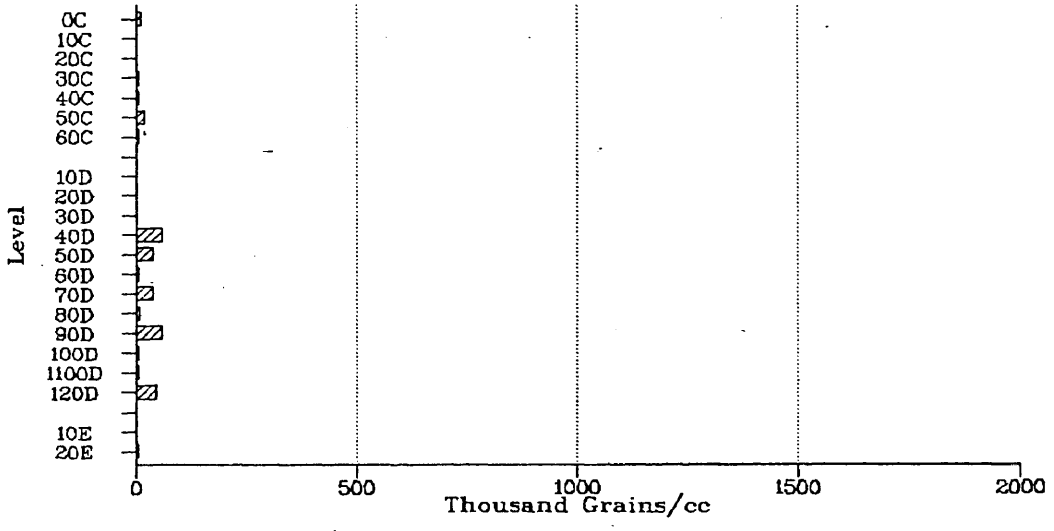

Text-Figure 91. Cupuliferoipollenites concentrations for Sequence C.



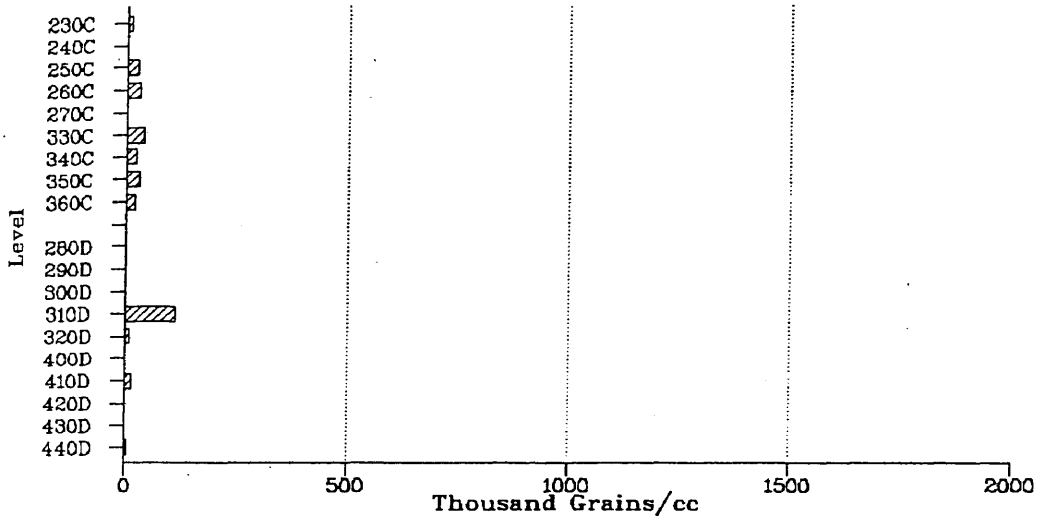

Text-Figure 92. Cupuliferoipollenites concentrations for Sequence G.



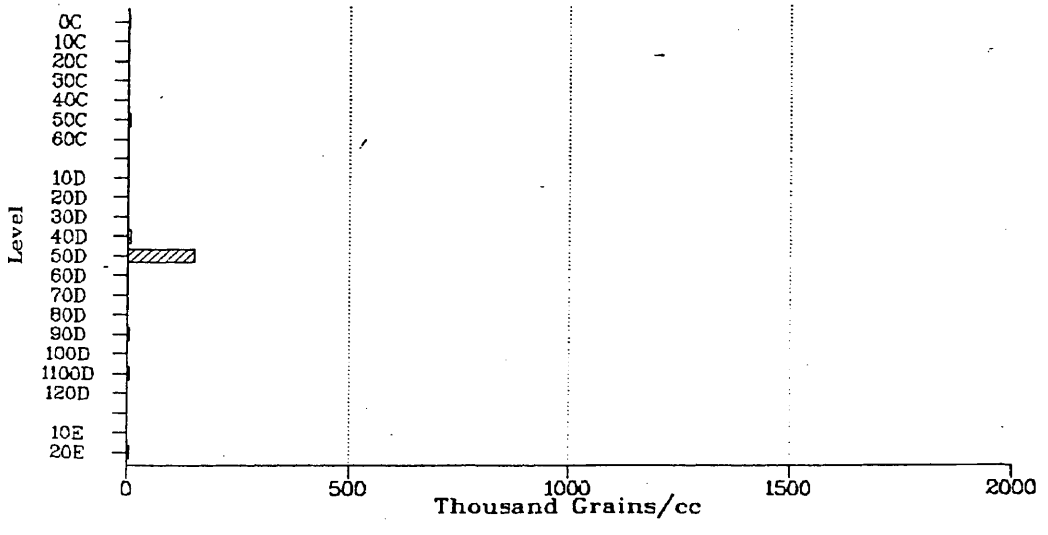

Text-figure 93. Momipites coryloides concentrations for Sequence C.



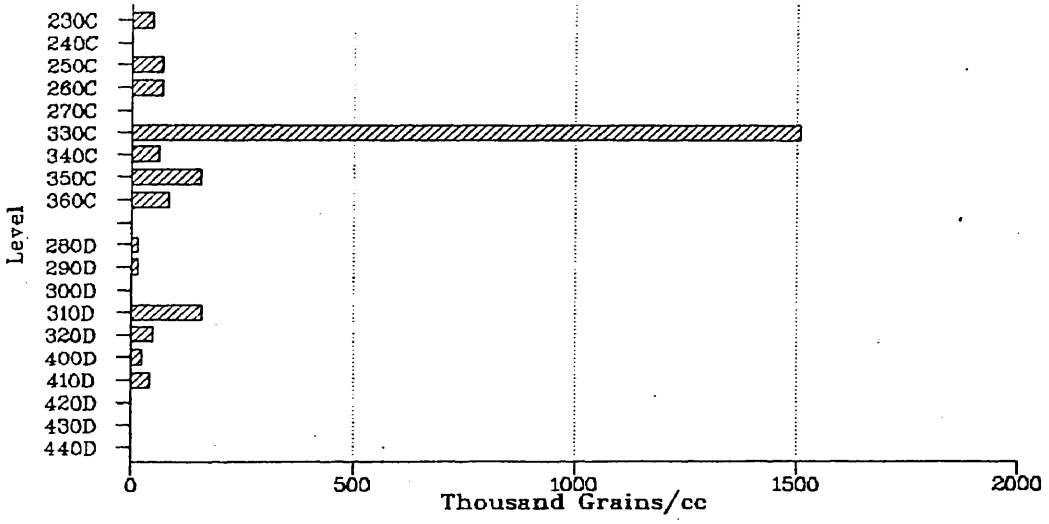

Text-Figure 94. Momipites coryloides concentrations for Sequence F.



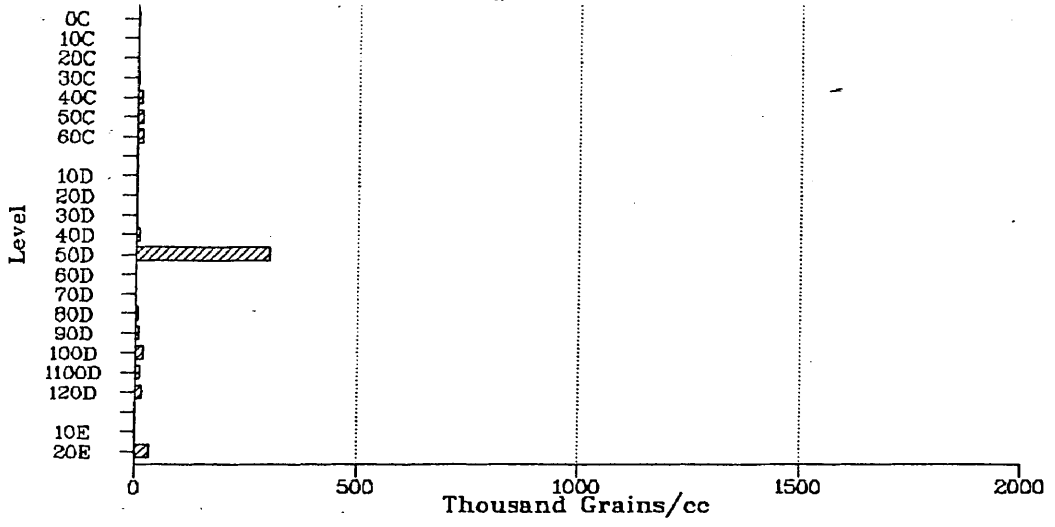

Text-Figure 95. Nyssa concentrations for Sequence C.




Text-Figure 96. Nyssa concentrations for Sequence F.




Text-Figure 97. Rhoipites angustus concentrations for Sequence C.




Text-Figure 98. Rhoipites angustus concentrations for Sequence F.

Rhoipites angustus concentrations are also low, but spike to high values in two samples, 330C in Sequence C and 50D in Sequence F. The R. angustus percentages for these two samples are higher than for adjacent samples but cannot be described as spikes.

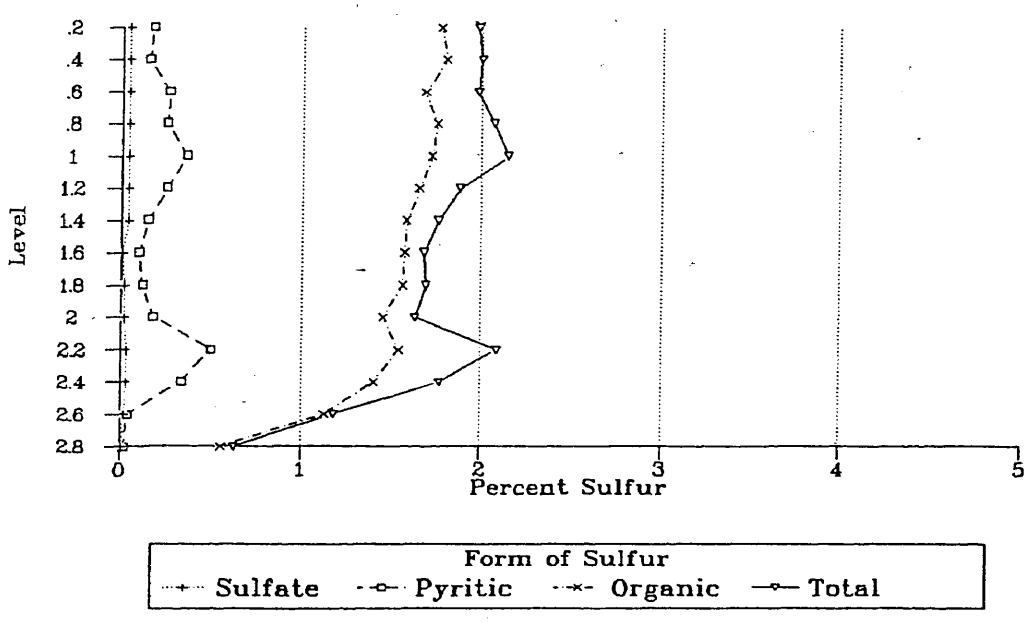
Concentration values for Nyssa are on the average the lowest of the four, and are especially low for Sequence F. Small peaks in concentration occur in sample 310D of sequence C and at 50D in sequence F.

The likelihood of a variable rate of sediment deposition (Moore and Webb, 1978) make these concentration sequences difficult to interpret. The higher concentrations in Sequence C, however, may indicate an overall slower rate of deposition in that part of the swamp than in the area where Sequence F was deposited. Concentrations are higher in the levels that are dominated by Cupuliferoipollenites than in those dominated by Nyssa, Rhoipites angustus, and Momipites coryloides. These high, variable concentrations suggest that Cupuliferoipollenites produced relatively large numbers of pollen grains and was present near the site of peat deposition. The lower, less variable concentrations of M. coryloides may indicate that this palynomorph came from outside the swamp.

## FORMS OF SULFUR ANALYSIS

### Introduction

Gowan (1985) obtained sulfur values, including sulfate, pyritic, and organic and total sulfur, from his station B in highwall section B at San Miguel (Text-Figure 99). This is the same pit highwall from which the sequence H samples of this study were taken. He found "...no variation for total sulfur..." in seams A and B. These values ranged from about 1.5% at the base of the B seam to just above 3.0% in the superadjacent




Text-Figure 99. Forms of sulfur at Highwall B station B. After Gowan (1985).

sample. According to Gowan "The pyritic sulfur for Seam A decreases downward with a corresponding increase in organic sulfur. Seam C shows an overall decrease in total and organic sulfur downward," (p. 59) which suggests that iron influx, not the presence of sulfur, limited pyrite formation. Organic sulfur made up an unusually high proportion (greater than 80%) of the total sulfur in his samples; he cited results of around 70% organic sulfur for the entire deposit, as determined by the Paul Wier Company of Chicago, IL.

Gowan hypothesized that the high sulfur in the San Miguel lignites was due to postdepositional infiltration of seawater. He used the distribution of total sulfur, particularly the decrease at the base of the C seam, to suggest that the source of the marine water was the overlying partings.

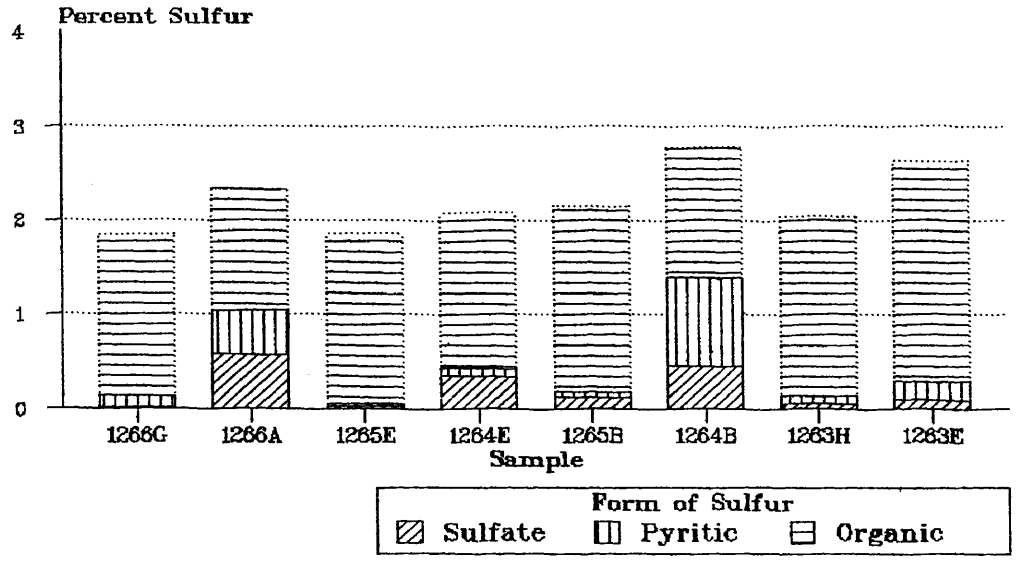
Given and Miller (1985) provided sulfur profiles of saline peats from Florida. These profiles exhibited sulfur proportions similar to those at San Miguel. Organic sulfur was by far the most important form, with up to about 4% of sediment weight, increasing dramatically in the middle of the core. Pyritic and sulfatic sulfur were generally less than 1%. One core, taken in slightly brackish water had greater amounts of pyritic than organic sulfur throughout its profile, and total sulfur was less than 2%.

Chou (1989), in his review of coal geochemical processes, put forth the view that most sulfur in medium and high sulfur coals (greater than 1% sulfur on an as received basis) is derived from the inundation of peats by seawater, both occasionally during peat formation, and during post-depositional transgression. Sulfur is introduced by marine transgression in the form of sulfate. Sulfate-reducing bacteria in peat take this

sulfate and produce $H_2S$. $H_2S$ in peat has two possible fates. 1) It may combine with reduced iron to form iron sulfide species, including pyrite, and 2) In the absence of iron, it can combine with organic compounds to form organic sulfur. However, it is important to realize that freshwater peats that have never been inundated with salt water could contain both pyritic and organic sulfur (Chou, 1989).

In these peats, organic sulfur may form during an initial phase of coal development, as plant material breaks down and reacts with elemental sulfur, polysulfides, and hydrogen sulfide. This plant sulfur can also combine with reduced iron, if any is available, to form iron sulfide. The amount of available iron may control the ratio of organic to pyritic sulfur in high sulfur coals. Thus the total amount of sulfur is probably more important than the forms of sulfur for determining depositional environments.

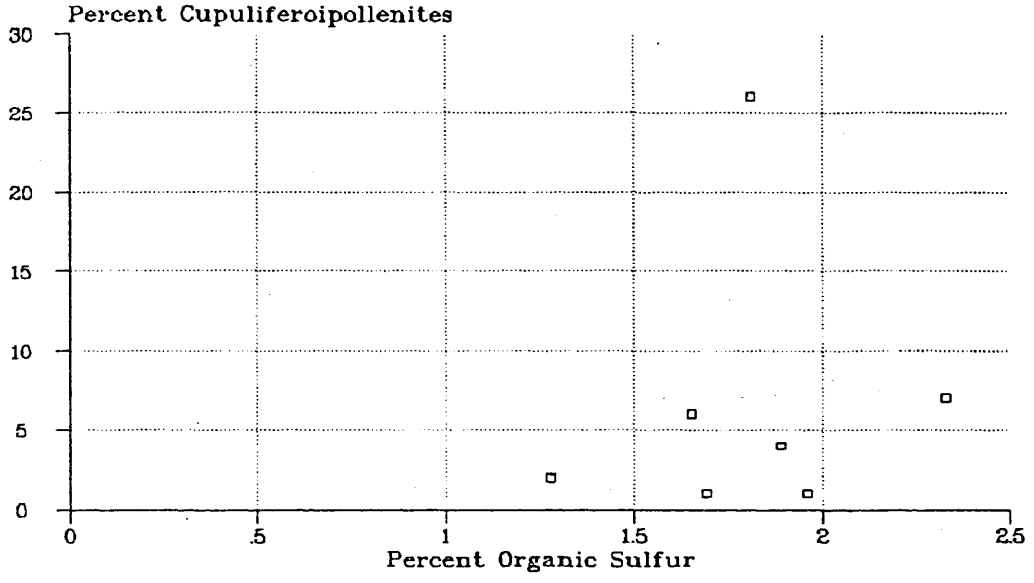
Forms of sulfur values given by Frederiksen (1981) from the Gibbons Creek Mine (Text-Figure 100) indicated that organic sulfur is also more abundant than pyritic sulfur at that locality. The total sulfur values ranged from 1.19 to 2.89%, comparable to many of the values from the San Miguel site. Frederiksen indicated that "Moderate amounts of organic sulfur...may suggest sulfur retention in halophytes, but so many other explanations exist for the presence of the organic sulfur in the coal so that little could be said about the environment of deposition of the peats." (p. 506-507). Although dinoflagellates occurred in overlying and underlying clastics, none were found in the lignites themselves. While Frederiksen considered the coals to have formed in "slightly brackish water," (p. 507) the dinoflagellates in the overlying beds may suggest a seawater source



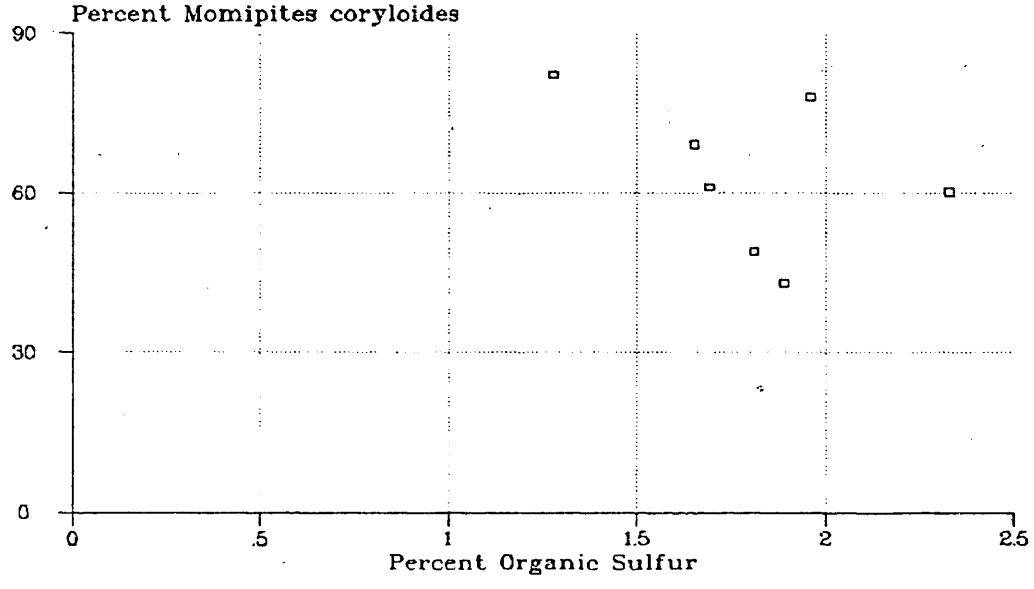

Text-Figure 100. Forms of sulfur in the Gibbons Creek Lignite samples of Frederiksen (1981).

of sulfur-bearing waters which infiltrated the Gibbons Creek coal beds.

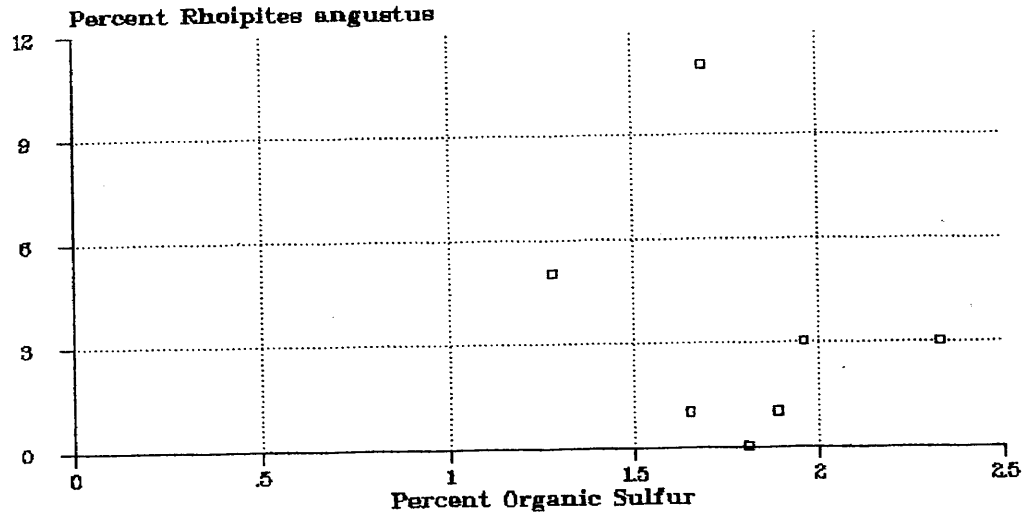
Plots of the Gibbons Creek organic sulfur values compared with Frederiksen's (1981) palynomorph values from the same site are shown in Text-Figures 101-103. Most of these plots show no correlation between sulfur and palynomorph percentages. A plot of Rhoipites angustus against total sulfur percentages, however, shows a widely spread inverse relationship as does a similar plot of R. angustus against organic sulfur. A plot of organic sulfur against Momipites also shows an inverse, widely spread relationship, but a plot of total sulfur against Momipites yields no statistically significant relationship.




Text-Figure 101. Organic Sulfur vs. Cupuliferoipollenites in the Gibbons Creek Lignites.




Text-Figure 102. Organic sulfur vs. Momipites coryloides in the Gibbons Creek Lignites.




Text-Figure 103. Organic sulfur vs. Rhoipites angustus in the Gibbons Creek Lignites.

## Results

Sulfur values from San Miguel are given in Table 10 and are graphed in Text-Figures 104-106. As shown in Text-Figure 107, dry and as received percent were determined to carry the same information, and all weights are expressed here as received.

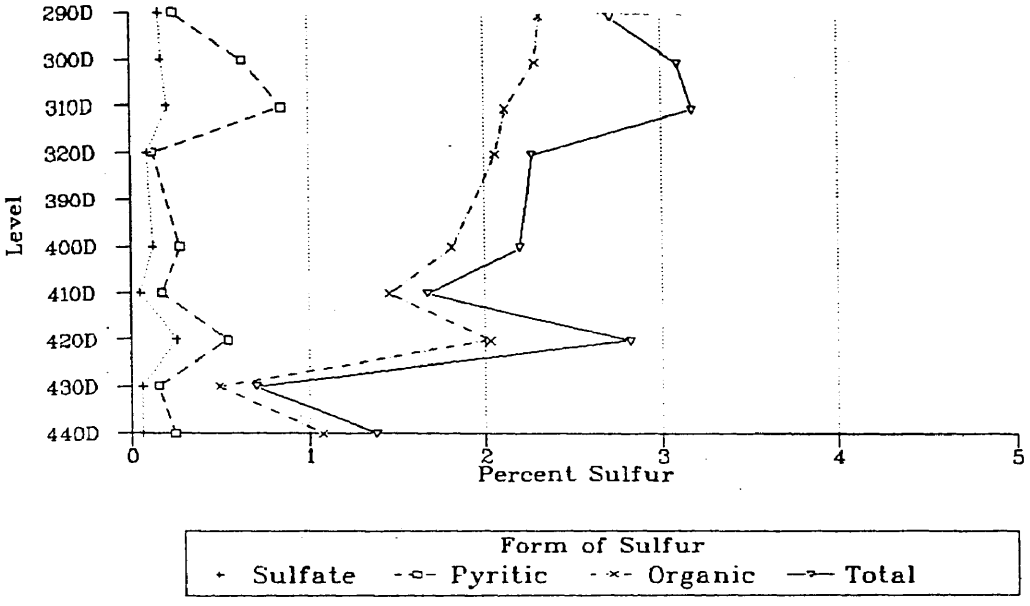
Most comparisons of palynomorphs and sulfur from San Miguel sequences also yield no coherent results (Text-Figures 104-121). Graphs of Momipites (Text-Figures 108-111) vs. organic sulfur may indicate a relationship, but this relationship does not hold in the C seam, nor in sequences C or G. A peak of organic sulfur values coincides with high percentages of the spores Cicatricosisporites and Laevigatosporites in the D seam of Sequence E, as well as with a local peak in Sequence C (Text-Figures 119-121). Peaks of these two palynomorphs coincide with an organic sulfur low in the D seam of Sequence G (Text-Figures 121). Some difficulties in correlating palynomorph and sulfur values may be due to an imperfect sampling technique. Sulfur samples were taken from areas directly above or below the pollen samples, rather than occupying a split of the sample removed for palynomorph analysis. In some cases, pollen content varies considerably between adjacent samples, and sulfur content may vary widely within a sample (Chou, 1989). There are, however, trends in both sulfur and pollen percentages which exhibit gradual changes, and the sampling procedure may have been accurate enough to provide a clue as to whether a relationship was indeed present.

Table 10. Sulfur Analysis of San Miguel Lignite samples.

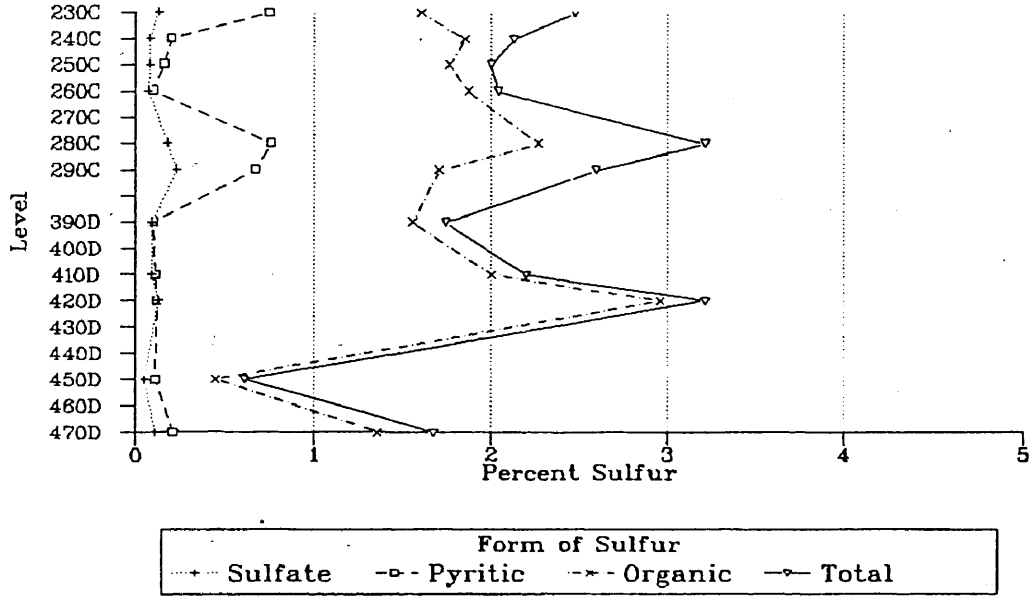
| Core/Sample | Sulfur Type | | | |
|---|---|---|---|---|
| | Total | Pyritic | Sulfate | Organic |
| (As Received) | | | | |
| C/D 290 | 2.72 | 0.24 | 0.16 | 2.32 |
| C/D 300 | 3.09 | 0.63 | 0.17 | 2.29 |
| C/D 310 | 3.17 | 0.85 | 0.20 | 2.12 |
| C/D 320 | 2.27 | 0.12 | 0.09 | 2.06 |
| C/D 400 | 2.20 | 0.27 | 0.12 | 1.81 |
| C/D 410 | 1.67 | 0.17 | 0.05 | 1.45 |
| C/D 420 | 2.82 | 0.54 | 0.25 | 2.03 |
| C/D 430 | 0.70 | 0.15 | 0.06 | 0.49 |
| C/D 430dup | 0.68 | 0.16 | 0.07 | 0.45 |
| C/D 440 | 1.37 | 0.24 | 0.06 | 1.07 |
| (As Received) | | | | |
| E/C 230 | 1.85 | 0.57 | 0.10 | 1.20 |
| E/C 240 | 1.55 | 0.15 | 0.06 | 1.35 |
| E/C 250 | 1.47 | 0.12 | 0.06 | 1.29 |
| E/C 260 | 1.48 | 0.07 | 0.05 | 1.36 |
| E/C 280 | 2.38 | 0.56 | 0.13 | 1.68 |
| E/C 290 | 2.02 | 0.52 | 0.18 | 1.32 |
| E/D 390 | 1.32 | 0.08 | 0.07 | 1.18 |
| E/D 410 | 1.70 | 0.08 | 0.07 | 1.54 |
| E/D 420 | 2.51 | 0.09 | 0.10 | 2.32 |
| E/D 450 | 0.52 | 0.09 | 0.04 | 0.39 |
| E/D 470 | 1.39 | 0.18 | 0.09 | 1.13 |
| (As Received) | | | | |
| G/D 10 | 6.01 | 0.75 | 2.51 | 2.75 |
| G/D 20 | 2.34 | 0.02 | 0.18 | 2.14 |
| G/D 30 | 2.58 | 0.04 | 0.28 | 2.26 |
| G/D 40 | 2.40 | 0.04 | 0.28 | 2.08 |
| G/D 50 | 2.66 | 0.06 | 0.52 | 2.08 |
| G/D 60 | 2.65 | 0.04 | 0.09 | 2.52 |
| G/D 70 | 2.28 | 0.25 | 0.25 | 1.78 |
| G/D 80 | 1.44 | 0.09 | 0.18 | 1.17 |
| G/D 80dup | 1.45 | 0.09 | 0.17 | 1.19 |
| G/D 90 | 2.30 | 0.13 | 0.28 | 1.89 |
| G/D 100 | 0.86 | 0.10 | 0.03 | 0.73 |
| G/D 110 | 2.02 | 0.25 | 0.47 | 1.30 |
| (Dry) | | | | |
| E/C 230 | 2.48 | 0.75 | 0.13 | 1.60 |
| E/C 240 | 2.13 | 0.20 | 0.08 | 1.85 |
| E/C 250 | 2.00 | 0.16 | 0.08 | 1.76 |
| E/C 260 | 2.04 | 0.10 | 0.07 | 1.87 |
| E/C 280 | 3.21 | 0.76 | 0.18 | 2.27 |

Table 10. Continued

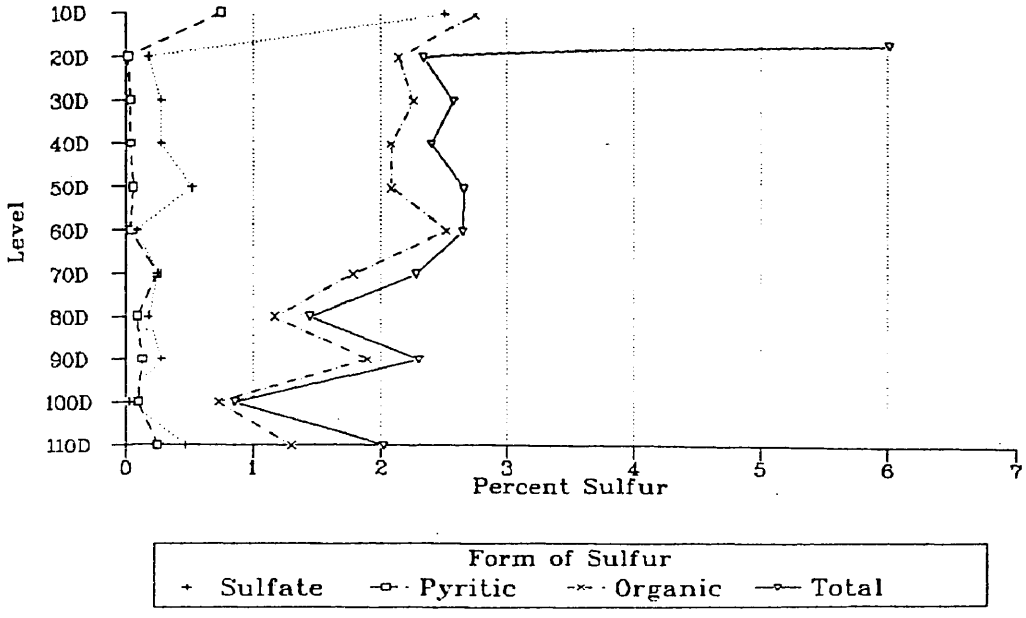
| Core/Sample | Total | Pyritic | Sulfate | Organic |
|---|---|---|---|---|
| E/C 290 | 2.60 | 0.67 | 0.23 | 1.70 |
| E/D 390 | 1.74 | 0.10 | 0.09 | 1.55 |
| E/D 410 | 2.20 | 0.11 | 0.09 | 2.00 |
| E/D 420 | 3.21 | 0.12 | 0.13 | 2.96 |
| E/D 450 | 0.61 | 0.11 | 0.05 | 0.45 |
| E/D 470 | 1.67 | 0.21 | 0.11 | 1.35 |



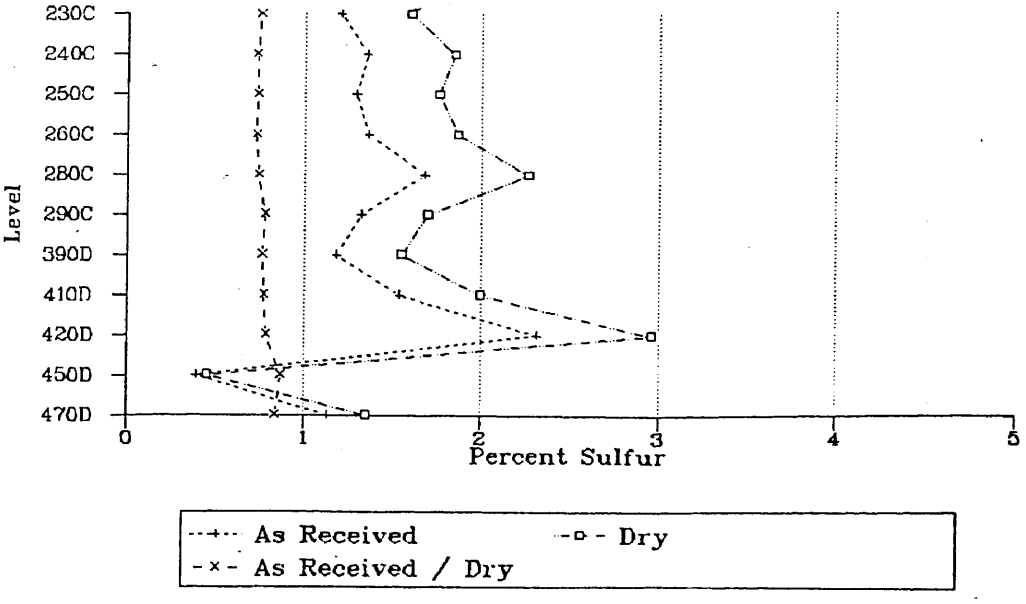

Text-Figure 104. Forms of Sulfur in Sequence C, San Miguel Lignite.



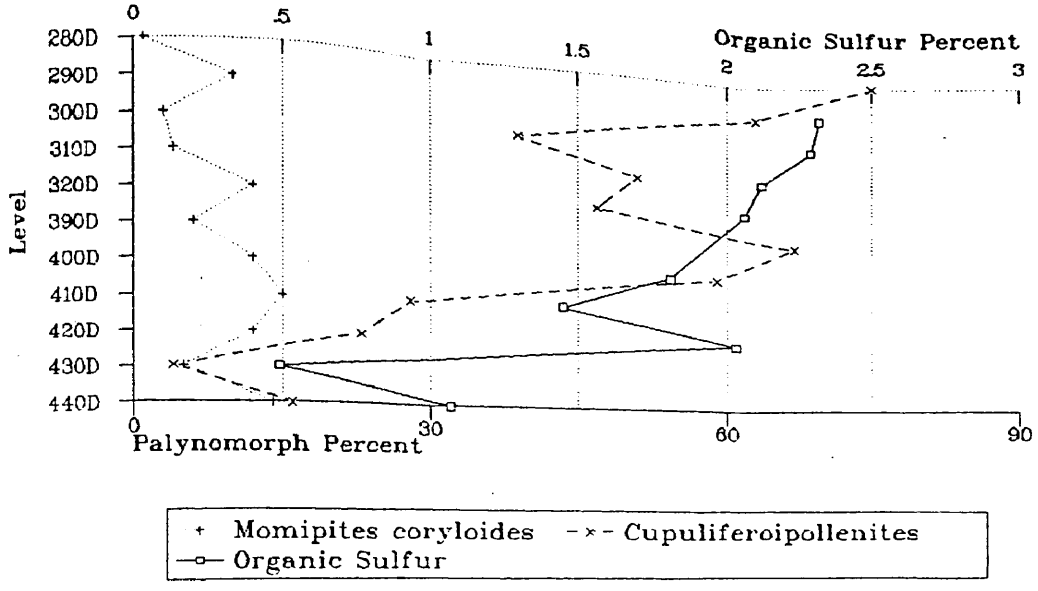

Text-Figure 105. Forms of sulfur in Sequence E, San Miguel Lignite.



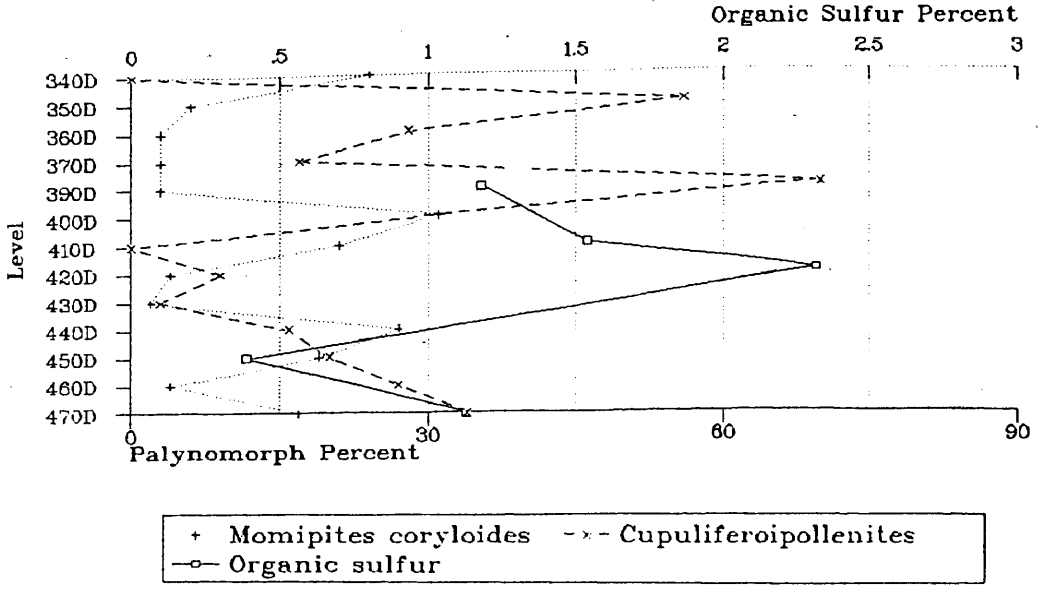

Text-Figure 106. Forms of sulfur in Sequence G of the San Miguel Lignites.



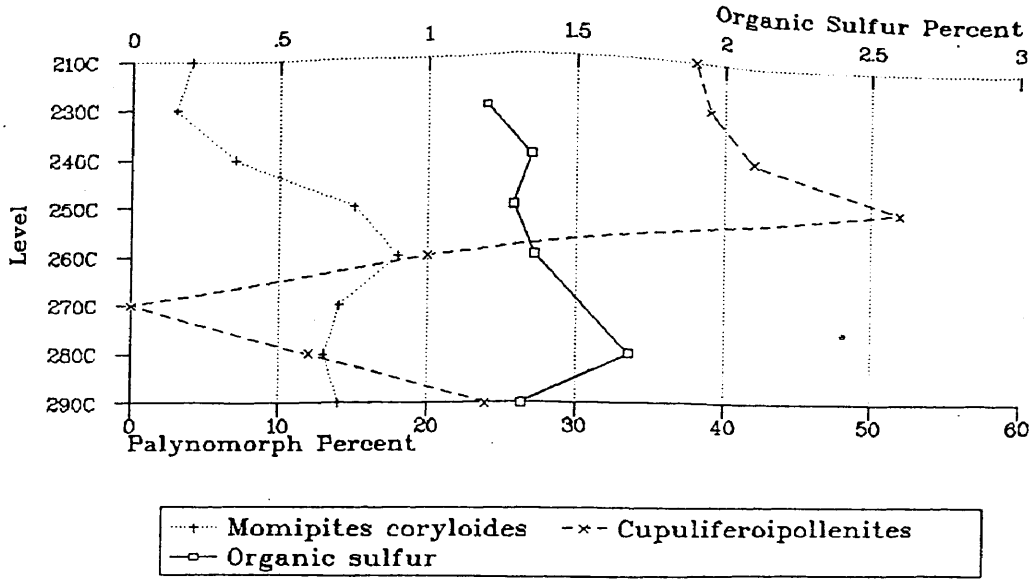

Text-Figure 107 "Dry" vs. "As Received" sulfur in the San Miguel Lignites.



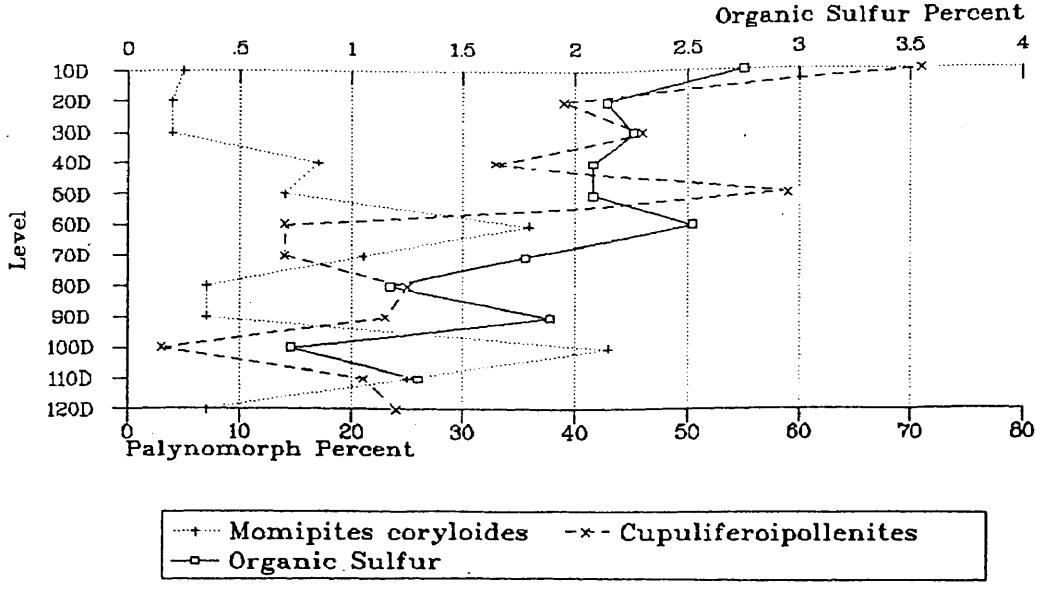

Text-Figure 108. Dominant taxa vs. organic sulfur in the D seam of Sequence C, San Miguel Lignites.



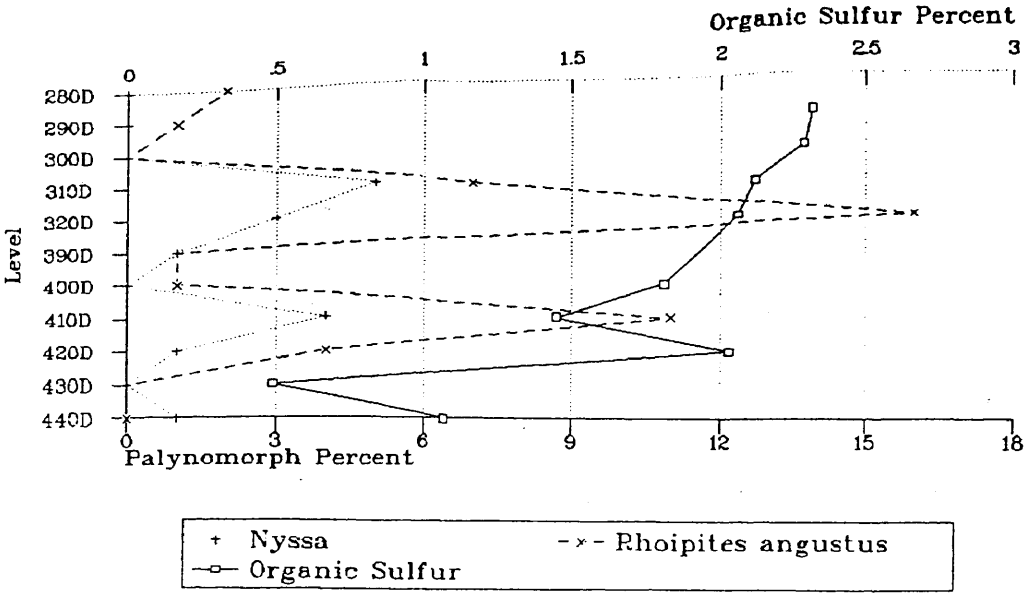

Text-Figure 109. Dominant taxa vs. organic sulfur in the C seam of Sequence E, San Miguel Lignites.



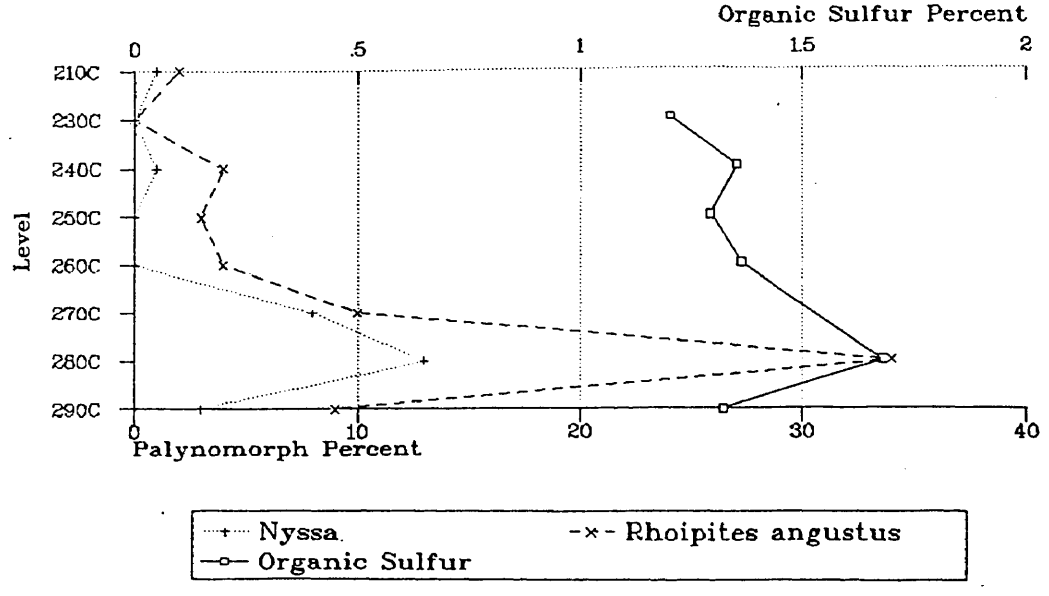

Text-Figure 110. Dominant taxa vs. organic sulfur in the D seam of Sequence E, San Miguel Lignites.



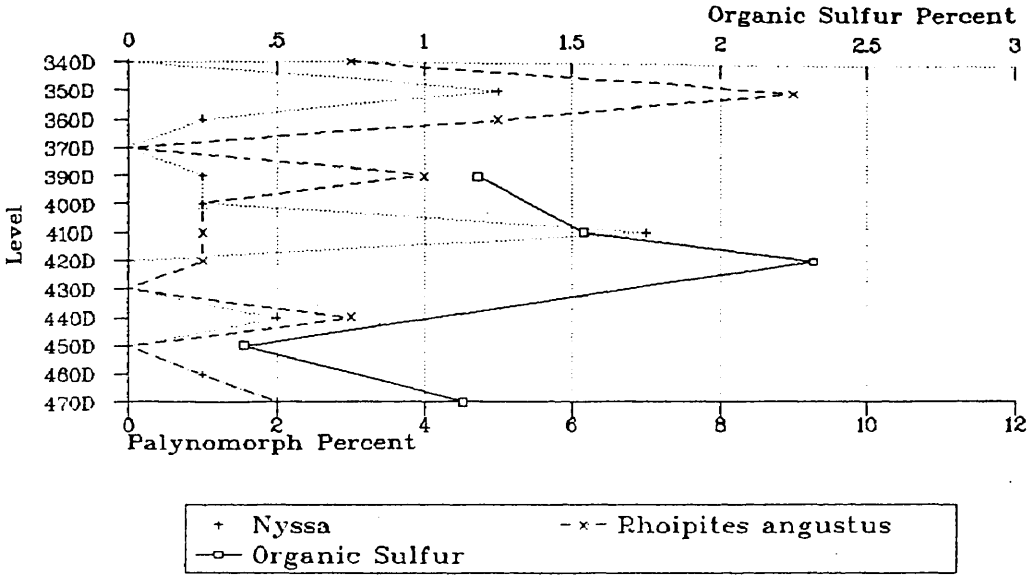

Text-Figure 111. Dominant taxa vs. organic sulfur in the D seam of Sequence G, San Miguel Lignites.



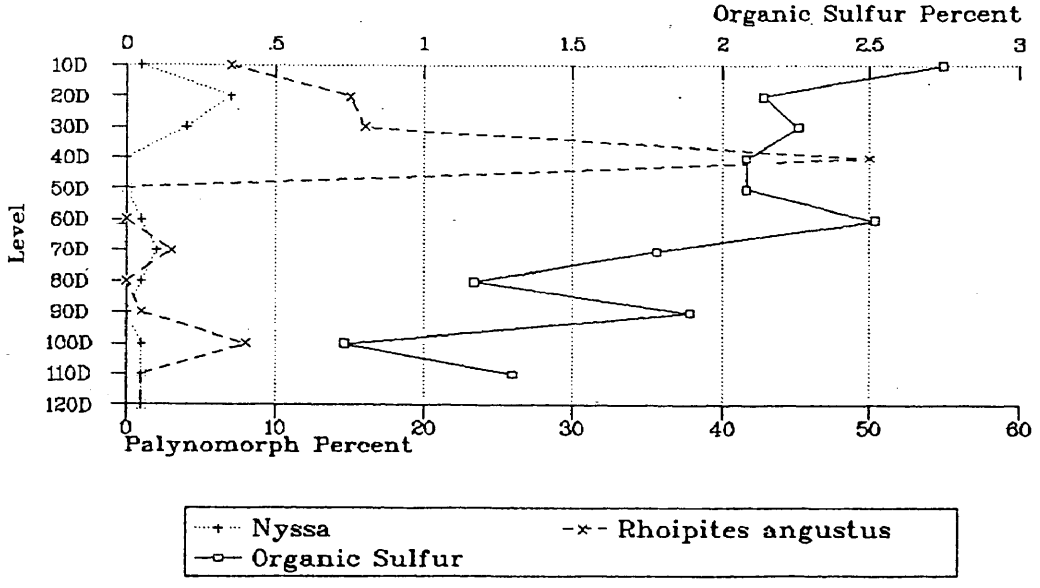

Text-Figure 112. Rhoipites angustus and Nyssa vs. organic sulfur in the D seam of Sequence C, San Miguel Lignites.



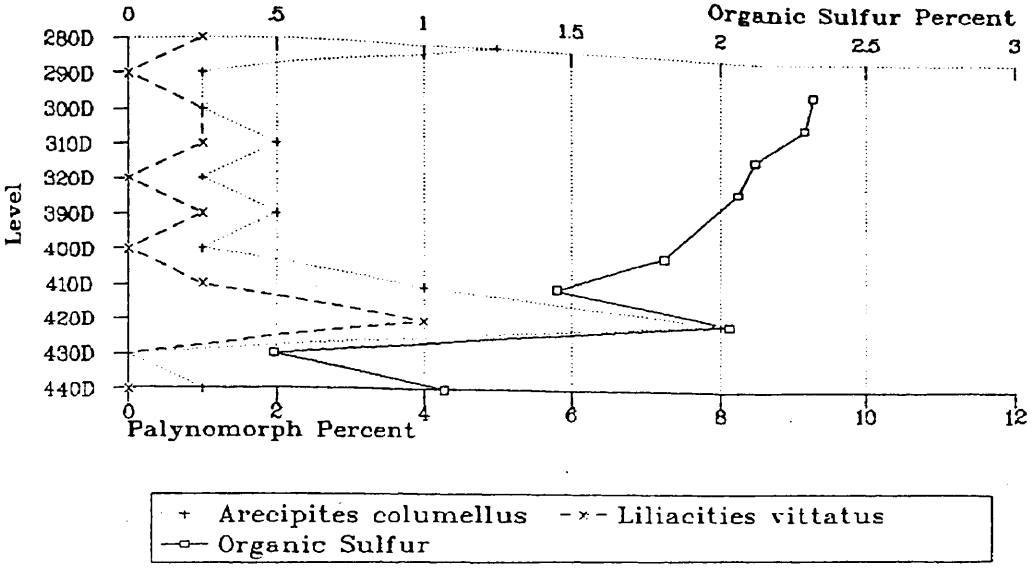

Text-Figure 113. Rhoipites angustus and Nyssa vs. organic sulfur in the C seam of Sequence E, San Miguel Lignites.



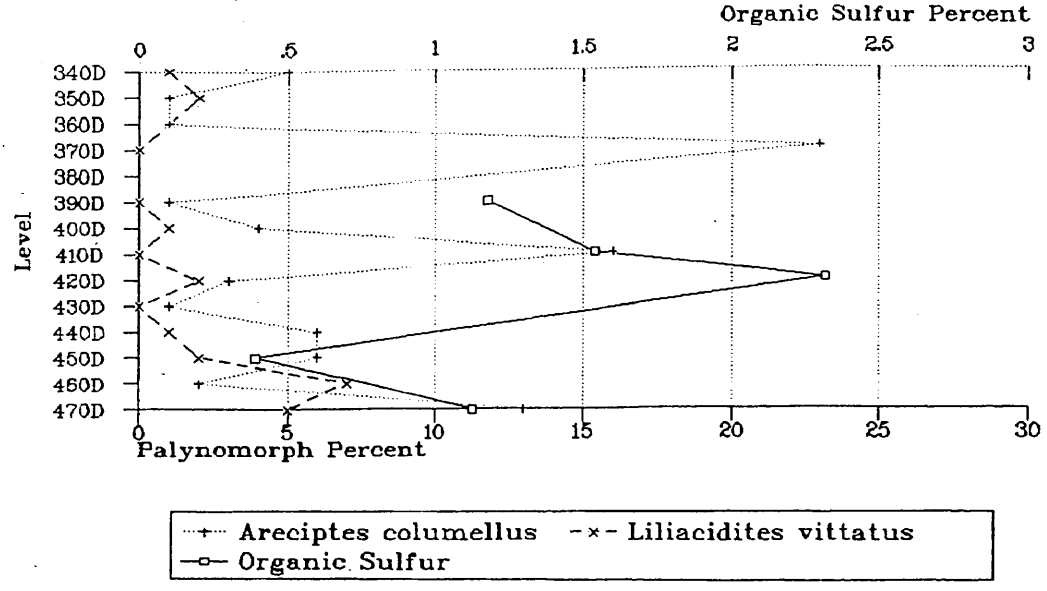

Text-Figure 114. Rhoipites angustus and Nyssa vs. organic sulfur in the D seam of Sequence E, San Miguel Lignites.



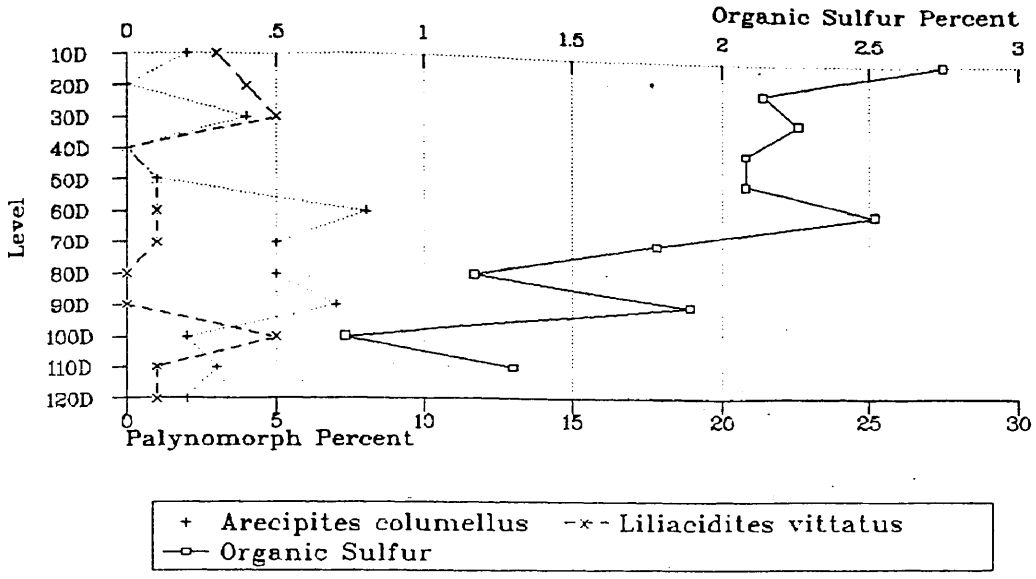

Text-Figure 115. Rhoipites angustus and Nyssa vs. organic sulfur in the D seam of Sequence G, San Miguel Lignites.



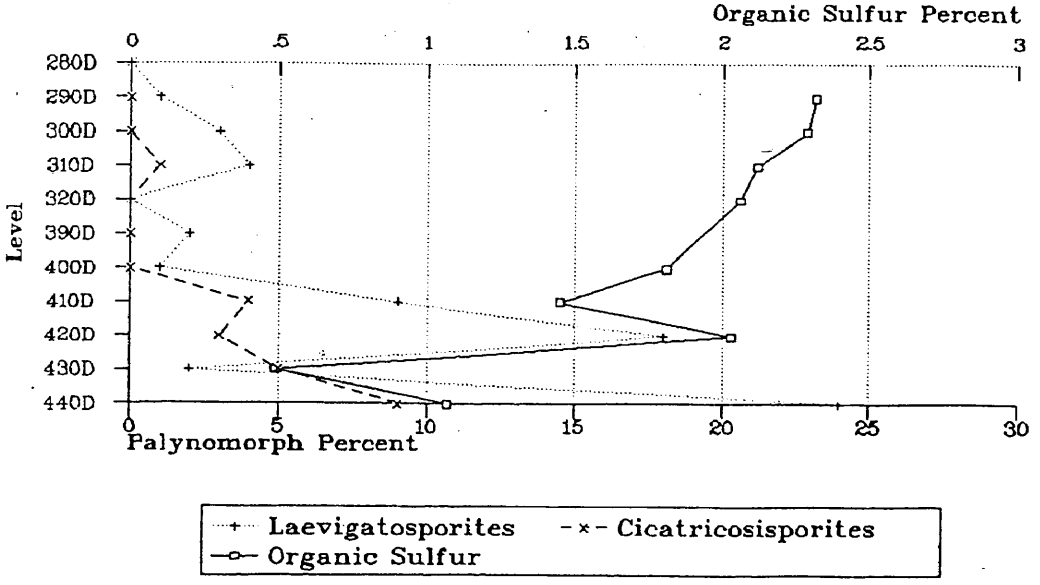

Text-Figure 116. Monocolpates vs. organic sulfur in the D seam of Sequence C, San Miguel Lignites.



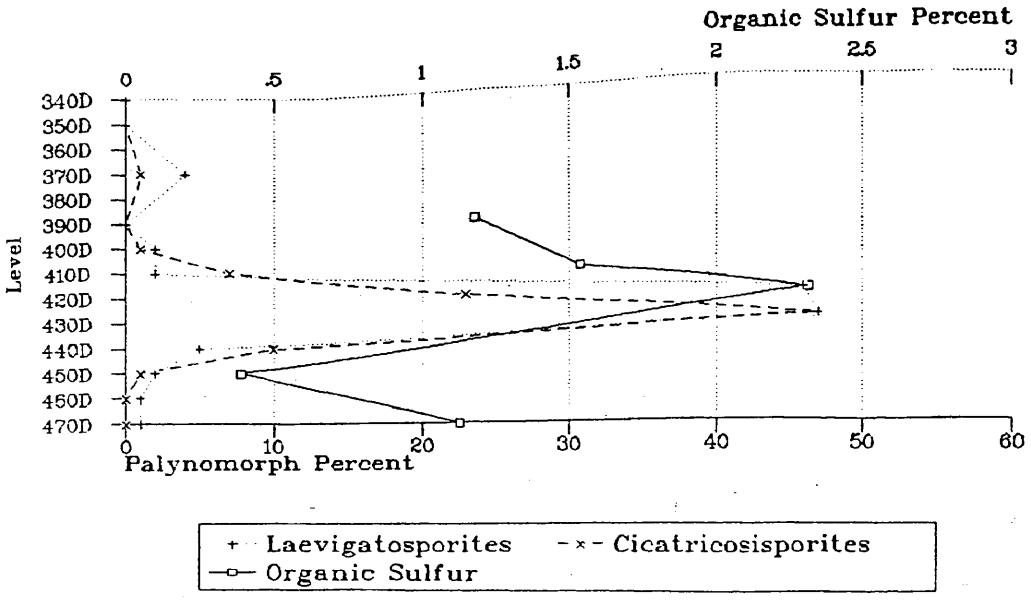

Text-Figure 117. Monocolpates vs. organic sulfur in the D seam of Sequence E, San Miguel Lignites.



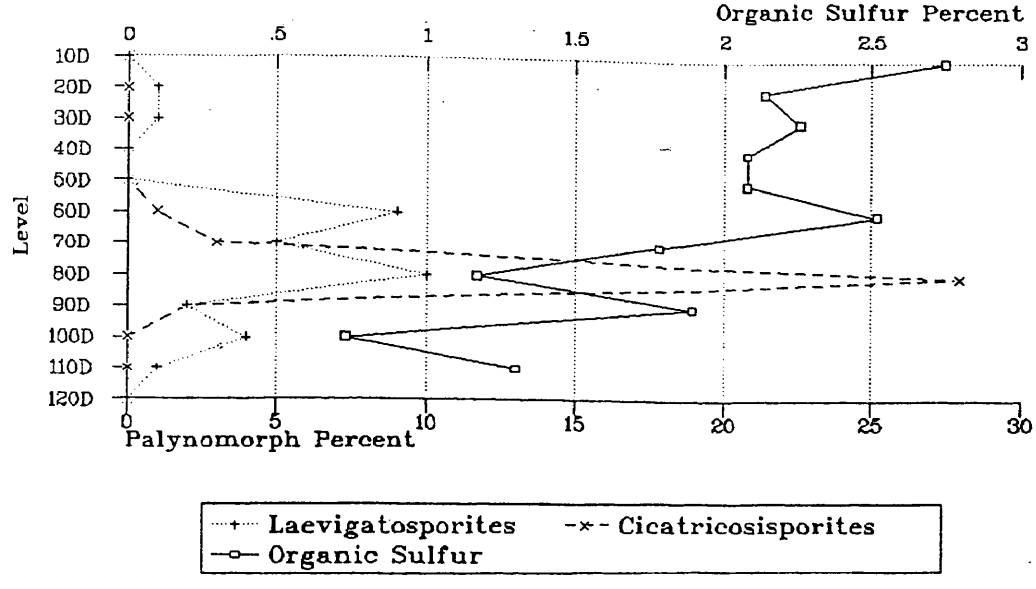

Text-Figure 118. Monocolpates vs. organic sulfur in the D seam of Sequence G, San Miguel Lignites.




Text-Figure 119. Spores vs. organic sulfur in the D seam of Sequence C, San Miguel Lignites.




Text-Figure 120. Spores vs. organic sulfur in the D seam of Sequence E, San Miguel Lignites.




Text-Figure 121. Spores vs. organic sulfur in the D seam of Sequence G, San Miguel Lignites.

I found no strong relationship between sulfur values and palynomorphs. Sulfur values drop irregularly towards the base in the D seam of cores G and D, which could very well indicate an overprint of sulfur derived from a postdepositional incursion of seawater during the time the C-D parting was formed. Even if highs in sulfur values within a given seam are coincident with invasions of a halophytic flora, seawater likely percolated downwards into the peats during these times. In these cases high sulfur values would also coincide with freshwater environments beneath.

# PALEOECOLOGY

Palynomorph diagrams and Reciprocal Averaging Analysis (referred to here as "RA") suggest that several plant communities lived at the San Miguel and Lake Somerville sites. RA plots (Text-Figures 25 and 26) further suggest that these communities were segregated along at least two environmental gradients. The gradients are represented on the first axis by the spores Laevigatosporites and Cicatricosisporites and some monocotyledons opposed to dicotyledonous taxa, and on the second axis by Nyssa, Rhoipites angustus, and Momipites coryloides opposed to Cupuliferoipollenites. Palynomorph diagrams indicate that of the second axis taxa, Nyssa and Rhoipites characteristically are most important near the base of seams, whereas Cupuliferoipollenites is often more important near the top.

These methods do not indicate the nature of the gradients. In order to define the gradients, it is necessary to examine the environmental requirements of the taxa on the continuum. This has been done successfully with modern vegetation (Clark, 1986), but it is more difficult to do with Early Tertiary taxa because the environmental requirements are poorly known. In the following discussion, I have used the term "Anchor" for taxa with ecologies and pollination mechanisms that can be hypothesized because of their affinities with modern plants. "Suggestor" refers to taxa with ecologies and pollination mechanisms which must be inferred by morphological and stratigraphic methods.

Anchors

RA plots from both San Miguel and Lake Somerville show Nyssa positioned near one end of the second axis (Text-Figures 25 and 26). Nyssa pollen peaks in these Eocene samples almost surely represent swamp trees growing at the sample site. The presence of both macrofossils and pollen in other lignites as reported by Eyde and Barghoorn (1963), Dilcher and McQuade (1967) and Van der Burgh (1967); the entomophilous pollination mechanism; and the present swamp habitat of Nyssa species support this assumption. There is also no evidence of Nyssa growing in brackish water. It is, however, impossible to speculate further on nutrient requirements, hydroperiod and water depth; Nyssa seems to be able to thrive in a wide range of swamp habitats and, furthermore, there is no assurance that an Eocene species would have the same micro-requirements as any modern genus.

Rhoipites angustus is Nyssa's "mystery associate" on both palynomorph diagrams and RA plots; it has a hypothetical affinity to Rhus, a shrubby pioneer on nonpeat soils. A morphology that, according to Wodehouse (1933) and Frederiksen (written commun., 1988), points to insect-pollination suggests that it too inhabited the peat-forming swamps at San Miguel and Lake Somerville. The pattern of distribution is related to that of Nyssa, but is slightly different; R. angustus peaks tends to lie slightly above those of Nyssa on some of the palynomorph diagrams given in this paper.

Chrysophyllum pollen from San Miguel and Lake Somerville closely resembles that of modern Chrysophyllum. It is seldom present in large quantities, and never really peaks in the San Miguel lignites, yet the entomophilous nature of modern-day

Chrysophyllum suggests that the grains actually represents a component of the San Miguel vegetation. Some modern species presently grow in periodically flooded swamp sites as well as on swamp hammocks. Chrysophyllum charts closer to Nyssa and Rhoipites angustus on the Lake Somerville RA plot, but lies closer to Cupuliferoipollenites than most taxa. On the San Miguel composite plot, it charts closer to Cupuliferoipollenites.

Cyrillaceaepollenites is another taxon with insect pollinated, swamp dwelling, modern analogs and it could easily be interpreted as a freshwater swamp taxon. These pollen grains, however, also resemble those of the modern mangrove Brugiera and may have a mangrove affinity. Cyrillaceaepollenites plots near the center of axis 2 on the composite RA plot from both the San Miguel and Lake Somerville deposits.

Ilex is also a modern genus which is insect-pollinated, has poor pollen dispersal, and grows in swamps, although it also grows in other habitats. Grains of Ilex pollen in a lignite probably implicate Ilex as a member of the paleoswamp community. It plots near the middle of the axis 2 continuum on RA diagrams from both Lake Somerville and San Miguel.

Tetracolporopollenites was almost surely insect-pollinated, and there is ample evidence both of Sapotaceous fruits found in lignites and of modern day swamp dwelling Sapotaceae (Berry, 1924; Pennington, 1990). The genus is never very common in the San Miguel and Lake Somerville floras, but moderate "spikes" of Tetracolporopollenites appear in the lignites. It plots very close to Cupuliferoipollenites on the San Miguel RA diagram, and is closer to Cupuliferoipollenites on the expanded Lake Somerville RA diagram.

Sabal and Arecipites lie closer to the spores on the first axis at San Miguel than most taxa. Both monocots show affinities to palmettos, which are insect-pollinated. Palmettos can grow on dry land, or in fairly wet areas, or they may be characteristic of swamp borders. A Claiborne-aged palmetto swamp hypothesized by Potter (1976) was thought to be a swamp border environment and represented a transition from a peat forming environment to "dry" land. In the San Miguel and Lake Somerville lignites, the peaks of both Arecipites and Sabal are totally contained in peat, and the palm swamps at these sites likely represent a different environment than those in Potter's Tennessee lignite.

It is likely that an increase in Arecipites or Sabal pollen indicates a shift to palm wetland, perhaps a palm swamp. The RA plots suggest that the environmental parameters of the palmetto genera were probably not in a direct continuum between Cupuliferoipollenites and Nyssa-Rhoipites angustus.

The short distance of transport and large size of spores strongly suggests that the Cicatricosisporites and Laevigatosporites plants actually lived in the wetland. In many modern environments, ferns grow in drier areas than other wetland plants or in light gaps left by falling trees and logging (Raymond, personal communication). It is more likely that in the Eocene, ferns took the place of marsh forbs; thus the spore peaks may represent marshes. The "ferns" also form the base of one of the seams at Lake Somerville, suggesting a role as pioneer. In any event, the spore peaks likely indicate some type of disturbance, whether it be newly opened land, fire, or long hydroperiod. Spores, notably

Cicatricosisporites and Laevigatosporites, also form the end member of axis 1, opposite most of the angiosperms.

Suggestors

Potter (1976) felt that the Cupuliferoidaepollenites grains in his Claiborne age lignite represented a dry land plant. Percentages were high in Potter's clastics, and it is likely that the pollen was wind-transported. It is not common in most of the San Miguel sequences, where it is also found in greater amounts in the clastics.

The true nature of the Cupuliferoipollenites pollen is difficult to discern. The higher values of this genus in the lignites at San Miquel and Lake Somerville, as well in as the European brown coals (Frederiksen, 1985) and Potter's (1976) Claiborne lignites from Tennessee, as opposed to the clastic layers, suggests that the parent plant actually lived in a peat forming environment. These values can be quite high, and the grains are common even in clastics, which likely indicates that the parent plant either manufactured substantial amounts of pollen, or was wind-pollinated, or both. As mentioned in the paleoecological notes, temperate species of Castanea, which has the same size and shape, are wind-pollinated. It is, however, possible that more than one species of parent plant is represented by Cupuliferoipollenites.

Liliacidites clusters with the spores as an end member on axis 1 of the San Miguel RA diagram, but not on the Lake Somerville RA diagram. On the Lake Somerville palynomorph diagram, obvious peaks of Liliacidites and Arecipites may occur coincident or

adjacent to one another. These peaks are also especially prominent in the D seams at San Miguel.

Although Liliacidites is clearly monocotyledonous, the affinity of Liliacidites grains is not further known, and it is difficult to assign any sort of environment to that genus on this basis. Elsik (1978) thought of the Liliacidites parent as a marsh plant, and it may be that it was a low, Paleogene equivalent of a marsh forb. On the other hand, it may have actually been a palm, and inhabited a palm swamp of the type described by Myers (1990). Both situations suggest a wetter, deeper water environment than would have occurred in a hardwood swamp. The environmental requirements of the Liliacidites wetland may have been similar to those of a fern marsh.

Caprifoliipites tantulus was thought by Frederiksen (1981) to have been insect-pollinated because of morphology. It is common in East Texas Jackson age swamp deposits including Lake Somerville, but it is not common at San Miguel. C. tantulus plots near Cupuliferoipollenites on the RA plot from San Miguel. At Lake Somerville, where it has definite peaks in the lignites which far exceed the amount in the clastics, C. tantulus plots with a large group of palynomorphs clustering with Nyssa and R. angustus. C. tantulus is never an important part of the San Miguel flora, where it is more abundant in the overburden samples.

Momipites is a common pollen grain in the Eocene; it has been linked with the Juglandaceous Engelhardia-Oromunnea-Alfaroa complex, but the environmental requirements of the parent plant are controversial. At Lake Somerville, M. coryloides is much more common in the lignite layers, yet it is also the most common palynomorph in the clastic sample. If the clastic

sample is hypothesized as marine, then substantial amounts of windborne M. coryloides must have been available. In the San Miguel E sequence, M. coryloides is in general more common in the clastic overburden. It is, however, common in the lignite in some samples where percentages of both Cupuliferoipollenites and Nyssa-Rhoipites angustus are low. M. coryloides makes up about 30% of the overburden pollen spectra, and it likely made up about 30% of the regional pollen rain; it has been theorized to be wind- pollinated but heavy. Perhaps the regionally derived M. coryloides in the lignites did not come from far away. It may have been coming from either "upland" or swamp parent sporophytes.

At least two species of Momipites are represented palynologically at San Miguel and Lake Somerville, indicating at least two species in the parent flora. Because the M. coryloides values are higher in the lignites than in the clastic samples at Lake Somerville, it is highly likely that at least one species of M. coryloides sporophyte lived in the Lake Somerville swamps and contributed a substantial proportion of the local pollen rain. M. coryloides is not abundant in the few levels dominated by Cupuliferoipollenites, suggesting that Cupuliferoipollenites either produced a very large amount of pollen, "drowning out" the input from M. coryloides, or that the environments in which the two taxa lived were mutually exclusive. Some of the M. coryloides pollen in the Lake Somerville lignites could also have been derived from a second species in the uplands. M. coryloides in the overburden could reflect a substantial and persistent population of dry land Momipites sporophytes in the vicinity. Frederiksen (1981) gave data from Gulf Coast Jackson age clastic samples indicating 30 to 40% Momipites in some samples,

and much lower percentages in others; in some Coastal Plain localities, the M. coryloides sporophyte must have been quite common.

The San Miguel lignites contain much less Momipites coryloides than the Lake Somerville deposit. In the C seam of sequence D, a M. coryloides peak occurs at the base in the place of the Nyssa and Rhoipites angustus peaks found in the other sequences. The percentages for M. coryloides are no higher here than M. coryloides percentages in the overburden of sequence E.

Momipites coryloides plots near the Nyssa/Rhoipites end of Axis 2 on the RA diagram for San Miguel. Perhaps it plots near Nyssa-Rhoipites because M. coryloides was part of the regional pollen rain transported into the swamp, registering as comparatively high percentages in the spectra because of the relatively low pollen production of the Nyssa- Rhoipites trees that were growing in the swamp, and possibly because many of the plants growing at the site were contributing even less pollen to the spectra than Nyssa-Rhoipites. At the base of the C seam in sequence D, the values for M. coryloides would be substantial because the fern marsh covering the landscape not only would produce relatively few palynomorphs, but because the lack of a tree canopy would allow more exotic M. coryloides pollen to reach the sediments. Confusingly, spore percentages are much higher and Momipites percentages lower in the "fern layer" at Lake Somerville. One interpretation for this difference is that at Lake Somerville, Cicatricosisporites ferns lived very close to the sampling site and shed substantial numbers of spores into the peat. The Lake Somerville habitat may have been more "fern intensive," whereas the San Miguel site may have been inhabited by not only

ferns, but by "silent" marsh taxa, which would decrease the proportion of spores to exotic palynomorphs in the sediments. In any case, Engelhardia-type peltate leaf hairs are occasionally found in very low quantities in the San Miguel lignites, and their presence suggests a local origin for at least some proportion of the San Miguel Momipites grains.

In the RA diagram from the Lake Somerville deposit, Momipites coryloides plots toward the center of axis 2, and only slightly towards the Nyssa-Rhoipites end of the continuum, reflecting its omnipresent nature in the peatland.

Quercoidites inamoense, which probably represents an oaklike plant, plots with Nyssa-Rhoipites on the San Miguel RA diagram, and is more plentiful at the base of the C seam in some sequences. Grains of this taxon are sometimes more numerous in the lignites than in the overburden, and it is possible that Q. inamoense represents an tree similar to a swamp oak with environmental requirements similar to that of Nyssa.

Other taxa, notably the possibly Fagaceous small tricolporates Siltaria and Araliaceoipollenites are often associated with Cupuliferoipollenites, or at least take the place of Cupuliferoipollenites in the upper part of the palynomorph diagrams. It is likely that these taxa had environmental requirements similar to those if Cupuliferoipollenites.

"Minor Taxa"

Many of the taxa, including some of the "anchors," described in the taxonomy section occur relatively infrequently in both the San Miguel and Lake Somerville

deposits. Most of these plot on the composite RA diagrams near the second axis in a relatively neutral position, between the Cupuliferoipollenites and Nyssa-Rhoipites poles but closer to Nyssa-Rhoipites. Some of the taxa are too rare to establish a pattern of occurrence. Others do not appear to follow any logical pattern despite an adequate abundance; these palynomorphs may represent plant taxa with broad environmental tolerances or they may exemplify the swamp mosaic concept, with pollen and spores from several neighboring communities making minor contributions to a palynomorph spectrum. Some palynomorphs, for example, may represent plants living on small patches of slightly higher ground and not plants that were actually living at the coring site. Some rare pollen types, such as Ephedra, may be grains of regional pollen transported for substantial distances.

Taxon Summary

The modern habitats of insect-pollinated "anchor" taxa strongly suggest a marsh to swamp continuum along axis 1 and a swamp continuum along axis 2. The "ferns" and Liliacidites plants along axis one likely lived in a marsh environment with relatively deep water all year long, although it is also possible that their presence was a reaction to disturbance. The dicotyledonous plants at the other pole of the axis lived in a swamp with a shorter hydroperiod. Palmetto swamps may have occupied an environment intermediate in depth between the two extremes.

Depth may have also been responsible for the polarization between Nyssa-Rhoipites angustus and

Cupuliferoipollenites along the second axis. Alternatively, other environmental determinants, such as nutrient availability and salinity, may have been responsible.

The interpretation given by both Snedden and Gowan for the San Miguel is that of a freshwater swamp. The appearance of so many swamp indicators throughout the diagram would tend to support this conclusion. Besides Nyssa, the swamp indicators, as discussed above and in the taxonomy chapter, include Ilex, Chrysophyllum, and Cyrillaceaepollenites. On the San Miguel composite RA diagram, they plot between Nyssa-Rhoipites angustus and Cupuliferoipollenites and they have no discernable pattern in relation to Nyssa on the palynomorph diagrams. Surface samples taken by Griffin (1975), Clark (1986), and Cohen (1975) in marshes, however, yield percentages of up to 3% of swamp indicator taxa; for example, Nymphaea peat in the Okefenokee Swamp had traces to 2% of Nyssa, Ilex, Itea, and Lyonia. These sites did, however, have swamp vegetation in the vicinity. If the swamp taxa were not present at the location at which the cores were later taken, there were almost certainly swamp species close by. Gowan considered fossil wood in the core to be evidence of swamp at the coring site. Additionally, I noticed large quantities of both monocot and dicot wood in the face of seam B.

## The History of the San Miguel Deposit and the Nature of Wetlands

A wetland is a mosaic of communities. The arrangement of vegetation within this mosaic is controlled by environmental parameters. For example, the concentric rings of vegetational associations in the oligotrophic domed swamps of Borneo are determined by nutrient availability (Bruenig, 1990). Pollen diagrams from these swamps show a succession of vegetational associations as nutrient availability decreases (Anderson and Muller, 1975).

Vegetational patterns in such temperate swamps as the Okefenokee Swamp of the southeastern United States are largely controlled by hydroperiod as well as nutrient availability and salinity. Additionally, fire, which destroys the peat substrate, is important in reestablishing open water communities (Cypert, 1972). Studies in swamps such as the Okefenokee indicate that the resulting plant communities can be discerned palynologically. (Cohen, 1975; Rich and Spackman, 1979).

### Scenario One: Shallowing

**San Miguel.** Multiple sequences taken from clastic marine or lake cores would be expected to be very similar to one another because the palynomorphs entering the sediments represent the regional pollen rain. Much more of the local component of vegetation is represented in cores from wetlands, and because of the mosaic-like nature of the vegetation, the sequences will all be different. Clark (1986) analyzed 66 cores from a coastal area on Long Island in order to adequately

reconstruct the historical changes in vegetation which resulted from the changing shoreline. The eight sequences from San Miguel are probably not sufficient to give a detailed picture of changes within the San Miguel paleowetland, but they do show general trends and some of the variation on the trends.

The changes in the C seam show an overall replacement of a Nyssa-Rhoipites swamp at the base to a Cupuliferoipollenites swamp at the top). Sequence A does not show this change; this may be because it is far to the southwest of the other sequences and is influenced by different processes.

Sequence D contains only a few percent of Nyssa and R. angustus at the base of the diagram, and their place is taken by Momipites and by spores. My interpretation is that the lower part of the C seam of Sequence D represents a fern marsh, that the ferns were producing relatively few palynomorphs, and that most of the Momipites grains coming in were from the "upland" vegetation. Palynomorph curves from the C seam of the closely adjacent Core C provide a good example of the replacement of Nyssa-R. angustus by Cupuliferoipollenites. Perhaps the base of sequence D represents a low spot and a small marshy area.

No real evidence exists as to whether Cupuliferoipollenites or Nyssa lived in deeper water. According to Gowan's model, Cupuliferoipollenites would have taken over at San Miguel as the swamp filled with peat and would therefore have lived in shallower water. Similarly, if the small Lake Somerville ponds were filling in with sediment, then the Cupuliferoipollenites plants would have the role of a short-hydroperiod, shallow-water plant invading at the end stage of infilling.

Following Gowan's scenario at San Miguel, a tidally influenced marsh vegetated by grasslike monocots was superseded upon barrier closure by a peat-forming freshwater swamp with Nyssa and Rhoipites angustus. Because these plants did not disperse large amounts of pollen, regional influx from Momipites is apparent in the diagram. Low areas were populated by fern marsh. As the water shallowed and the swamp filled in, fagaceous Cupuliferoipollenites trees "took over," until finally the barrier was breached again, peat formation ceased, and a new marsh formed, to be preserved as a parting. At the site of sequence A, in the southwestern part of the swamp, Cyrilla shrubs may have originally occupied the site, to be rapidly replaced by Cupuliferoipollenites plants. Just prior to the opening of the barrier, there may have been subsidence or a rise in the water table leading to population of that site by the deeper water taxa Nyssa and Rhoipites angustus.

The D seam vegetational sequence at San Miguel is more problematic and probably involved alternation between various types of swamp and marsh. The fluctuations are most similar between the adjacent sequences E, F, and G, and involve somewhat disorderly temporal juxtapositions of palm swamp, fern marsh (represented by a "fern spike" near the base of D), Cupuliferoipollenites swamp, and Nyssa-Rhoipites swamp. Except for the palm swamp, these are the same communities found in the C seam.

If these vegetational changes were caused by water depth fluctuations, the fluctuations were too complex to have been regulated simply by a single barrier closure. Other controls, for instance drought, fire, or base level change, may have been responsible the fluctuations. Unfortunately, there are no time line

markers, and it difficult to discern if the vegetational changes were contemporaneous between sites.

A spore maximum appears in the upper half of the lower half of seam D in diagrams E, F, and G. Perhaps this "fern" maximum was a high water event throughout that part of the paleowetland. A spore maximum also occurs at the bottom of sequence C; this maximum may have been the result of the same event, with peat deposition commencing later at the Sequence C site.

Peat oxidation with pollen degradation took place in the upper half of the D seam in four of the five sequences (C, E, F, G); this event may have been contemporaneous throughout that part of the swamp. The oxidation may have been caused by fire or drought.

**Other Seams.** There are relatively few samples from the thinner seams. Pollen spectra from available samples of the A seam probably represent Cupuliferoipollenites-dominated swamp. One sample contains quite a bit of Momipites; perhaps Momipites was actually growing in the A seam swamp, as it probably grew in the Jackson age swamps of East Texas. The single spectrum for the B seam also suggests a Cupuliferoipollenites swamp.

Samples from the E seam in sequence E suggest a palm swamp, whereas the E seam sample from the F sequence suggests Nyssa-Rhoipites swamp. It appears that the E seam accumulated in a diverse and short-lived freshwater swamp.

**Partings.** Gowan believed that the partings were tidal flats with marsh vegetation. His evidence came from the abundant grasslike macrofossils, which represent a local marsh flora. There is very little grass pollen and no sedge or rush pollen in the San Miguel flora. Pollen from these taxa is rarely found in

Eocene rocks, so it is difficult to say exactly what monocotyledonous plants are represented by these lathlike macrofossils, or what environment they may have represented. The pollen spectra from the partings contain the same species as those from the seams and overburden; some are similar in content to the overburden and are dominated by Cupuliferoidaepollenites and Momipites grains from the regional flora. Some spectra contain large percentages of Cupuliferoipollenites, and one contains an unusually high amount of Araliaceoipollenites granulatus. Gowan also found a dicotyledonous leaf in the C/D parting of sequence D, indicating nearby swamp vegetation; in fact, his model for vegetated tidal flats in the Niger Delta (Allen, 1970) involved mangrove swamp rather than salt marsh. The varying proportions of Cupuliferoipollenites and Cupuliferoidaepollenites probably are related to proximity to swamp vegetation, but there is no obvious pattern in these samples.

**Lake Somerville.** A similar but more complex sequence exists in the Lake Somerville seams. The Lake Somerville lignites are a much smaller deposit than the San Miguel lignites. During peat deposition, the vegetational zones may have been more compressed, and the vegetational gradient steeper.

The palynomorph spectrum from the base of the middle (top) seam lead to an interpretation of a fern marsh pioneering a clastic substrate as peat formation began. As the pond became shallower, a Caprifoliipites shrub swamp, and, later, a Rhoipites angustus swamp formed. Following these communities, initiation of a palm swamp may have been a response to an increase in water level, or the water may have continued to become

shallower. Finally, a Cupuliferoipollenites swamp grew as the lake filled in.

The lower seam is slightly different. According to palynomorph evidence, a palm swamp was the first community to have inhabited peat in the paleowetland. A fern marsh may have been the initial peat forming vegetation in this seam, but the palynomorph evidence may have been missed in sampling because the marsh was short-lived. As shallowing continued, a Nyssa-Rhoipites swamp formed, followed by a Caprifoliipites shrub swamp, another palm swamp, and again a Caprifoliipites shrub swamp as water levels fluctuated. In the end, Cupuliferoipollenites trees colonized the wetland as the pond finally filled in.

Because Momipites coryloides percentages are higher in most of the spectra from the seams, it is likely that a species of Momipites tree was present somewhere in the small wetland during all stages of development, except at the very top.

Scenario Two: Deepening

A difficulty exists with the shallowing scenario for the Lake Somerville site. According to unpublished sequence stratigraphy work done by Yancey (1992), although marine regression probably allowed shallowing at least in the basal part of the Lake Somerville peats, a marine transgression likely occurred within the seams which would result in a rise in base level and flooding of the swamp. Although, as observed in some Carboniferous swamps, this situation may have yielded a deepening only at the top of the seam (Raymond, 1983), paleovegetational interpretations of the Lake Somerville

seams would most likely place this deepening between the Nyssa-Rhoipites and Rhoipites swamps and the palm swamps. In this scenario, Cupuliferoipollenites represents a plant thriving in the deepest water.

Transferring these paleovegetational interpretations to the San Miguel lignite presents a story which conflicts to some extent with Gowan's (1985) hypothesis. In this scenario, peat formation would have commenced with a Nyssa-Rhoipites community. Base level would have risen while the Nyssa-Rhoipites community was dominant. Cupuliferoipollenites would have become the dominant tree at a particular site as the water level rose, but the rise would to have been slow enough to maintain the communities and for peat formation to continue. Eventually, the water level would have risen to such an extent that salt water entered the system, and marsh vegetation established on tidal flats.

Peat deposition may, nonetheless, have been initiated in both the C and D seams by barrier formation. Base level would have had to change at least twice during deposition of the D seam, probably coincident with the "parting" between DRL and D.

Inundative vegetational sequences are not uncommon in wetlands, especially in coastal areas, even without a change in sea level. Bacon (1990) reviewed wetland swamp successional sequences in Guiana and noted that in coastal areas dammed by sandbars there may be increased flooding of the wetland instead of a gradual drying out of the land surface. He cited an example in Cayenne where "marsh forests" were changing to "swamp forests" as the frequency and depth of inundation increased. Also cited were fluvial swamps where, as levee height increased, water level increased in the swamps. Clark (1986) found historical evidence of increase in water

depth with shoreline changes and inlet openings in his palynological study of the Long Island coastline. Kedves (1960) hypothesized a transgressive sequence in a coal seam from the Hungarian Eocene, with a replacement of Taxodiaceae-Cupressaceae by palms and then by upland Sequoia pollen.

Scenario Three: Mangroves

A difficulty with portraying Nyssa and Rhoipites angustus as shallow water plants, and Cupuliferoipollenites, palms, and "ferns" as inhabiting deep water is found in the RA plots. Nyssa and Rhoipites plot as a continuum on axis 2, whereas both taxa and numerous associates plot against the common ferns and palms on axis 1. The plots suggest that two types of environmental gradients are involved. One of these gradients is probably water depth and hydroperiod. Possibilities for the second gradient include nutrient availability and salinity.

Vegetational zonation in the raised swamps of Borneo are controlled by nutrient availability; as the vegetation becomes more removed from sources of nutrients by the buildup of peat, xeromorphic species tolerant of this condition become more prominent (Breunig, 1990). Although there was no doubt some degree of community change due to nutrient availability, there is no reason to believe that the San Miguel wetland was a raised swamp and that nutrient poor Cupuliferoipollenites woodlands were the end product of peat build-up. The primary evidence against the San Miguel deposit representing a raised swamp is that it has an unusually high ash content, whereas raised swamps

are low ash deposits; the lack of "ash" influx is the cause of poor nutrient status in these wetlands.

S. Srivastava (oral commun.; 1990) suggested that some of the palynomorphs from the San Miguel samples resemble mangrove pollen. One of these rogue grains, Cyrillaceaepollenites, strongly resembles Bruguiera as illustrated by Thanikaimoni (1987) as well as a slide labeled "Bruguiera sp." from "British East Africa" (#2279) in the Mobil Oil Pollen Reference Collection at Texas A&M. It is also notable that Fechner (1990) found evidence that Cyrillaceae pollen from her Moroccan Eocene assemblage represented a salt marsh plant.

Frederiksen pictured Cupuliferoipollenites identical with Cupuliferoipollenites grains recovered from the San Miguel lignites in his 1981 paper. Included in this paper are data from the Jackson age Gibbons Creek lignites, which are thought to have been deposited in a brackish environment. Frederiksen did not find evidence for brackish water vegetation in this deposit. However, small tricolporates, including Siltaria, from the Texas sites investigated both by Fredrickson and myself resemble not only Castanea, but also Aegiceras, a mangrove taxon in the Myrsinaceae. An identification of Cupuliferoipollenites and other small tricolporates as fagaceous is, in fact, not supported by isolation from an inflorescence. Hypothesizing Cupuliferoipollenites as a mangrove, or as a brackish water taxon would suggest that the transition from Nyssa to Cupuliferoipollenites in the San Miguel deposit was the result of marine transgression, with sea level rising slowly enough for the continued deposition of mangrove peats.

On the San Miguel pollen diagrams, there is no discernable relationship between Cyrillaceaepollenites

and Cupuliferoipollenites, and the Cyrillaceaepollenites plots near the center of the composite RA diagram. On the Lake Somerville diagram, however, Cyrillaceaepollenites percentages are highest near the tops of the seams, where Cupuliferoipollenites is also most abundant. In the RA diagram, Cyrillaceaepollenites plots further towards the Cupuliferoipollenites end of the continuum than almost any other significant taxon. The data collected by Frederiksen (1981) from the Gibbons Creek lignites also show a strong co-occurrence of Cyrillaceaepollenites and Cupuliferoipollenites.

## Paleoecological Conclusions

A totally satisfactory interpretation of the Eocene paleovegetation at the San Miguel and Lake Sommerville sites is difficult to effect for several reasons. One difficulty inherent in the nature of the data. The palynomorphs that are shed into the fossil record are imperfectly representative of the parent vegetation because of differential production, transportation, and preservation. A plant type which may be dominant in the vegetation may be totally unrepresented in the fossil record and while community changes may be expressed on a palynomorph diagram, the full nature of the vegetation is rarely discernable.

Secondly, while the traverse of sites parallel to the strike of the deposit (that is, parallel to the shoreline) is useful for showing the amount of variation present in the San Miguel sequences, a traverse perpendicular to the paleoshoreline would have been useful in the interpretation of data. If a salinity gradient were present, a sequence close to shoreline

would contain a larger proportion of levels with salt tolerant environments and species; an inland sequence would depict more freshwater habitat.

None of the scenarios is perfect. The two freshwater scenarios do not offer sufficient environmental parameters to explain the two important gradients expressed by the RA diagrams. According to these scenarios, no reason exists for the flora to have shifted with changing depth to Nyssa or Cupuliferoipollenites swamp rather than palm or fern vegetation. Vegetational community response is, however, difficult to predict in modern habitats. In the salt water scenario, no concrete proof exists that either Cupuliferoipollenites or Cyrillaceaepollenites represents a mangrove. Pollen of the mangrove palm Nypa is present only in the clastic sample from Lake Somerville and not in the lignites; Lygodiumsporites adriennis, which may represent the brackish-water fern Acrostichium, is a very rare taxon in the lignites. No other "mangrove pollen" with modern analogs exists in any of the samples.

A third difficulty exists in the lack of published detailed palynomorph diagrams from the Upper Eocene. Neither Martinez-Hernández et al. (1980) nor Frederiksen (1981) presented stratigraphic detail. Upper Eocene palynomorph data also exists from Latin America, but these floras differ markedly from the Texas floras.

Martinez-Hernández et al. (1980) indicated that the Yegua-Jackson lagoonal-estuarine Miguel Aleman lignites deposits in the Rio Grande Valley of Mexico were characterized by Momipites, as well as Cicatricosisporites. Elsik (1986) also noted the abundant Momipites in a Yegua-Jackson lignite in Zapata County, Texas, but believed these grains to have been

blown into a marsh environment, and this may also have been the case at Miguel Aleman. The data from these two western sites are neither extensive nor quantitative, but hints that a regional pollen rain laden with Momipites coryloides contributed to the pollen flora both at these sites and at San Miguel. Because of its greater extent and more complex environmental conditions, the San Miguel deposit contains not only a "silent" marsh flora dominated by regional pollen, but also a more complex local swamp flora.

The overall flora of the San Miguel deposit also differs from the floras from the Lake Somerville and the Gibbons Creek Mine (Frederiksen, 1981). Most of the difference lies in the interpreted presence of Momipites, the higher percentages of Caprifoliipites and Salixipollenites and the low values for Cupuliferoipollenites at the East Texas sites. These differences may be the result of a climatic gradient from east to west Texas. Alternatively, they may be due to a habitat difference between the deltaic lignites of East Texas and the "lagoonal" lignites of West Texas, or to time-related plant migrations. Not enough data have been gathered to discern between these choices.

The spectra from both Lake Somerville and Gibbons Creek (Frederiksen, 1981; Gennett, unpublished data) contain palynomorph associations similar to those present at San Miguel, but with different frequency. Levels with relatively high percentages of Nyssa, palms, and spores exist at all three sites. No samples were discovered at Gibbons Creek with dominant levels of Cupuliferoipollenites. There is no evidence, however, that any of the Gibbons Creek samples were taken from the seam tops; the high levels at Lake Somerville were from samples taken at the top of seams. These

similarities suggest that, despite the absence of a Momipites association at San Miguel, many of the conditions and plant associations which existed at the East Texas sites also existed at San Miguel.

The most floristically comparable and data intensive Upper Eocene sequence is from the Dorog Basin of Hungary (Kedves, 1965). Taxodiaceae pollen is dominant in the lower seam, and there is little Nyssa. At the top of the seam is a palm peak with Monocolpopollenites tranquillus, which is rare in the San Miguel. The peak may represent a palm swamp analogous to those at San Miguel and Lake Somerville. The top seam is dominated by Cupuliferoipollenites cingulum, in an abundance roughly reciprocal to that of the Taxodiaceae. Perhaps the Taxodiaceae, rarely found in Gulf Coast Eocene lignites, co-occurred with Nyssa in the Late Eocene swamps of Hungary, as it does in the Mississippi Delta swamps today, and formed an environmental continuum with the Cupuliferoipollenites plant.

# CONCLUSIONS

The problems encountered in the study of the San Miguel lignites mirror the lack of comprehensive, coordinated studies on Gulf Coast Tertiary plant paleoecology. The complex vegetational history of these lignites suggests that, as with modern peats, neither a lignite seam of any thickness nor a deposit of any extent can be simply described in terms of environment of origin based on a limited number of samples. The complexity further suggests that perhaps chemical and petrological studies should be made with more systematic detail in order to correctly interpret environmental history. In most cases, sufficiently detailed studies have not been done and this has led to a lack of a regional framework in which to place the results of this study. This dearth has in turn made the San Miguel deposit more difficult to interpret.

In trying to find an interpretation for the San Miguel lignites, I explored several relatively uncharted techniques. The collection of horizontal samples indicated a substantial amount of lateral variation in the lignite flora, and the use of running averages allowed a comparison of variation in vertical and horizontal samples. As a result, most of the major changes in the San Miguel sequences could be assumed to be real whereas many of the minor changes could be reasonably assumed to be random.

Multivariate techniques were used effectively to explore the ecology of the species in this study. The key to the utilization of both cluster and reciprocal averaging analysis seems to have been the examination of sufficient samples to eliminate random variation.

Reciprocal averaging not only hinted at ecological relationships between taxa, but suggested strong similarities between samples in the same sequence, in many cases stronger than those between similarly placed samples in different sequences.

The techniques described above were, as discussed in the "Methods" section, for the most part "borrowed" from Quaternary palynology. These techniques would have been even more useful were it possible to determine more closely the affinity and ecological requirements of Eocene palynomorphs. Pollen concentration would have proved more useful if time horizons were available.

Given the nature of the existing paleoecological and stratigraphic framework of Gulf Coast Eocene lignites, I was able to suggest scenarios for the origin of the San Miguel lignites, but could not establish a "correct" scenario. Future work, and work in progress by other researchers may help clarify the choices. Very recently, for example, K. Phillips (Oral Commun., 1993) found two genera of marine diatoms in Lake Somerville samples laterally equivalent to my clastic sample, which strongly suggests salt tolerant vegetation in the upper sections of the Lake Somerville seams.

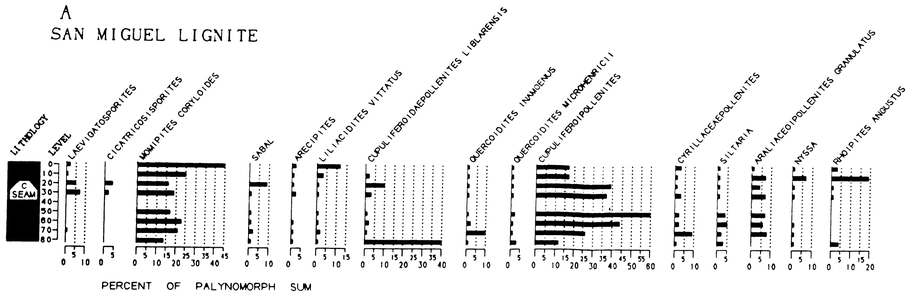
The importance of the San Miguel and Lake Somerville data is that it forms an established starting point with which to compare future work. This conclusion reflects not only a desire on my part to provide data to other workers, but to explore palynologically other sites from the Gulf Coast Eocene in a systematic and thoughtful manner in order to establish a better palynoecological framework.

# PLATE 1

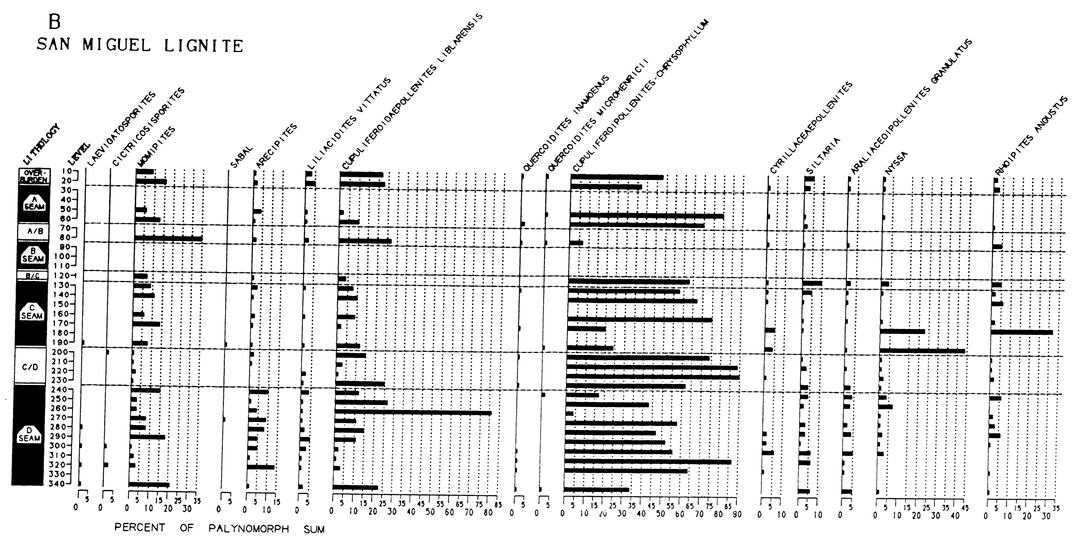
## MAJOR TAXON

## PALYNOMORPH DIAGRAMS

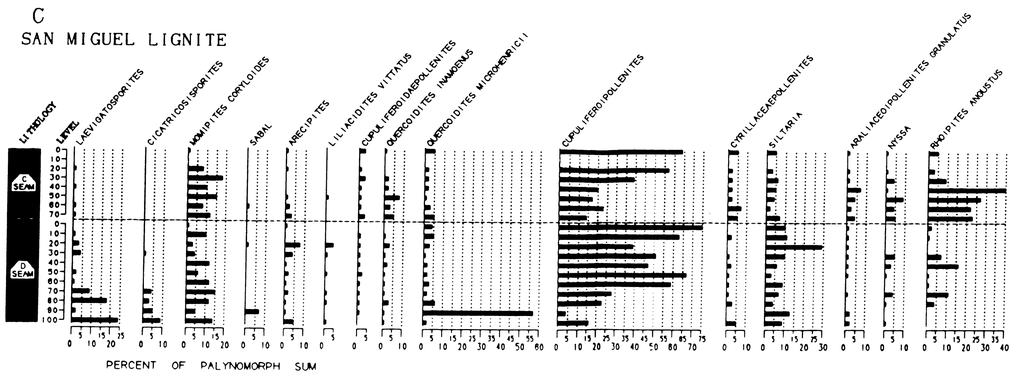
A
SAN MIGUEL LIGNITE




B
SAN MIGUEL LIGNITE




C
SAN MIGUEL LIGNITE

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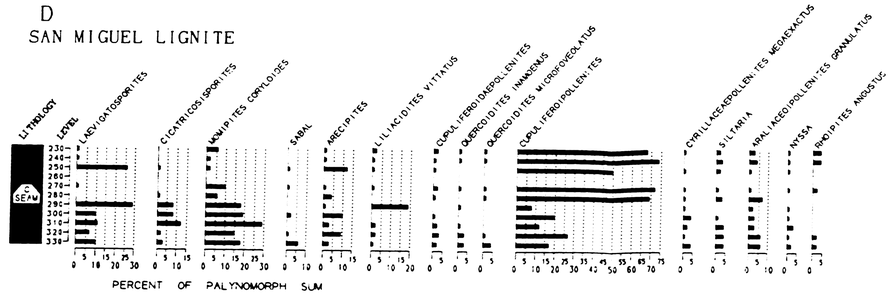
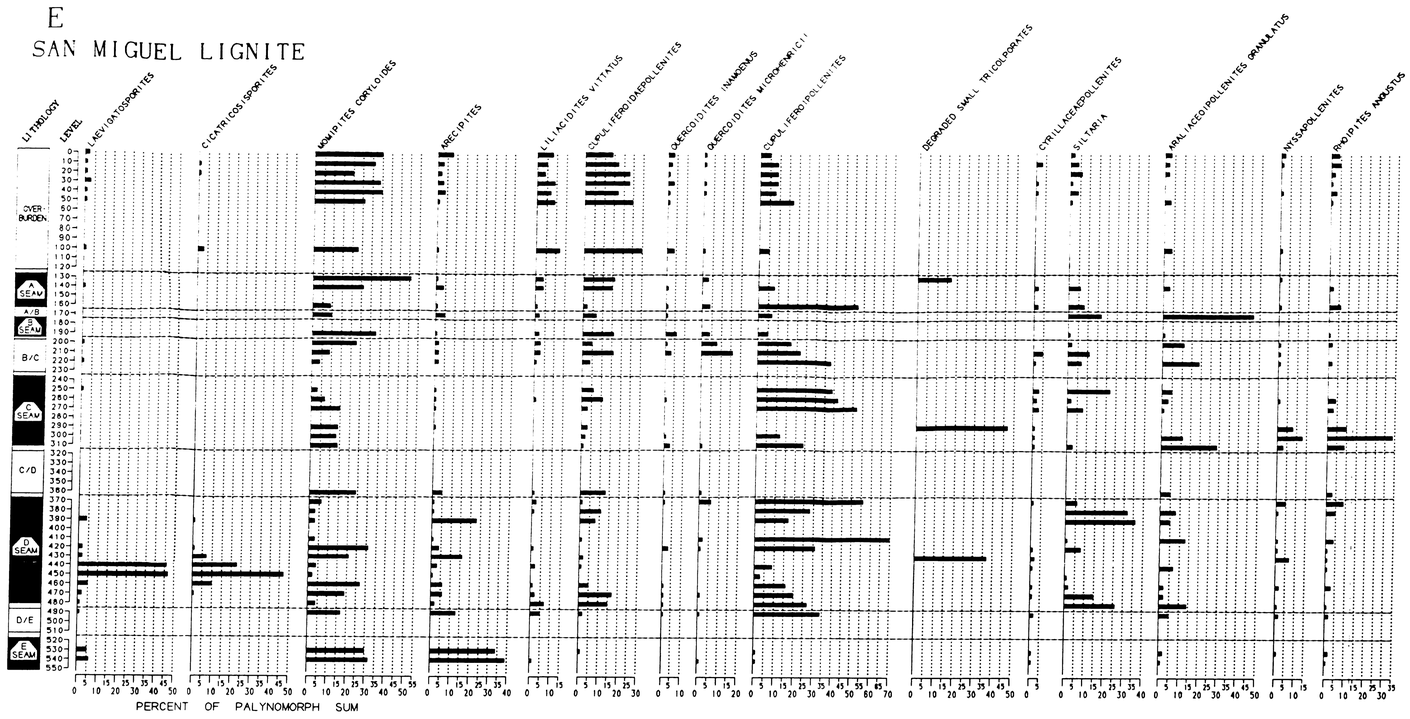
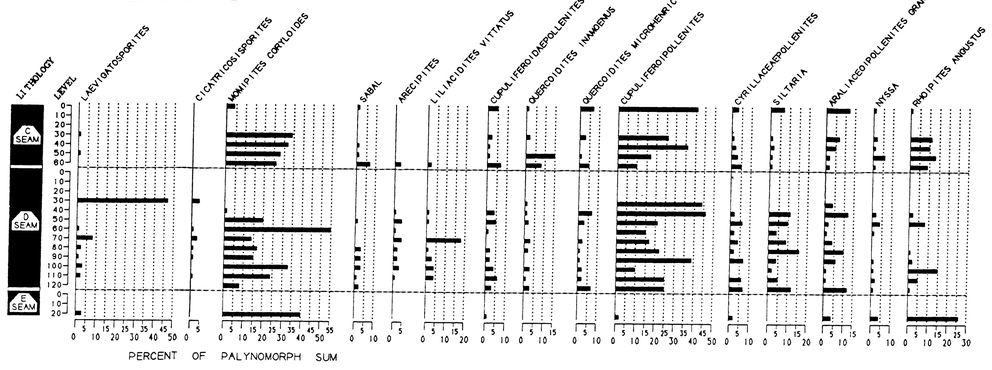


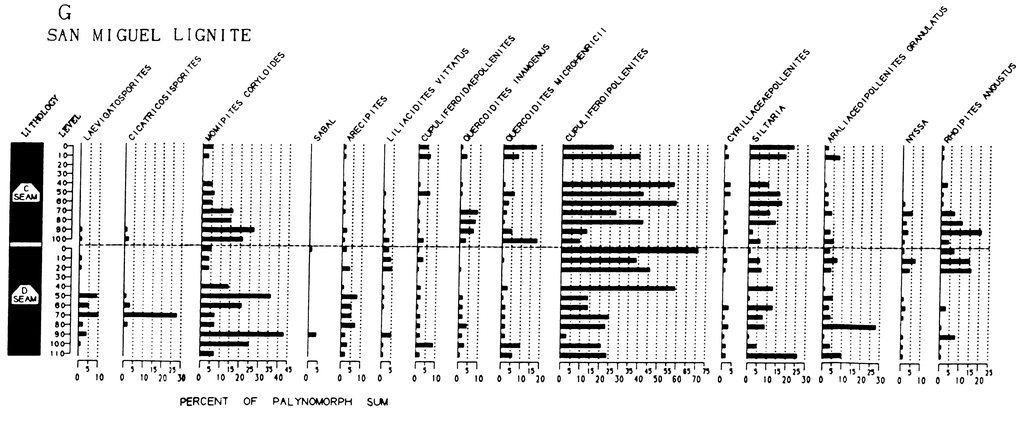

E
SAN MIGUEL LIGNITE



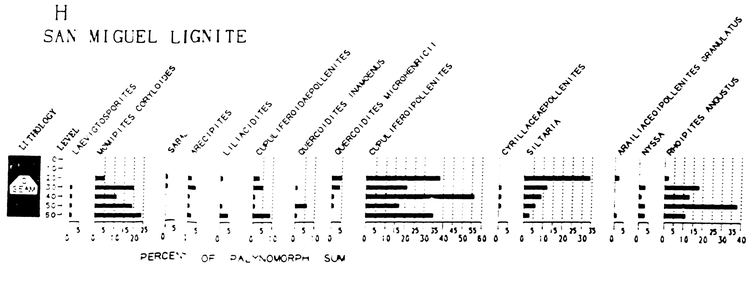

F
SAN MIGUEL LIGNITE




G
SAN MIGUEL LIGNITE




H
SAN MIGUEL LIGNITE

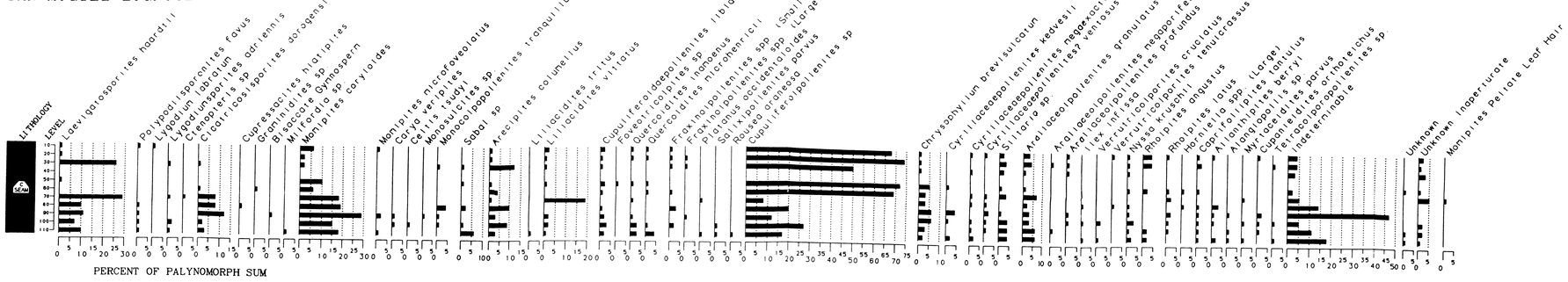



Judith Ann Gennett
1993

PLATE 3

# COMPLETE PALYNOMORPH DIAGRAMS OF D, E, AND F SEQUENCES

SEQUENCE D
SAN MIGUEL LIGNITE




SEQUENCE E
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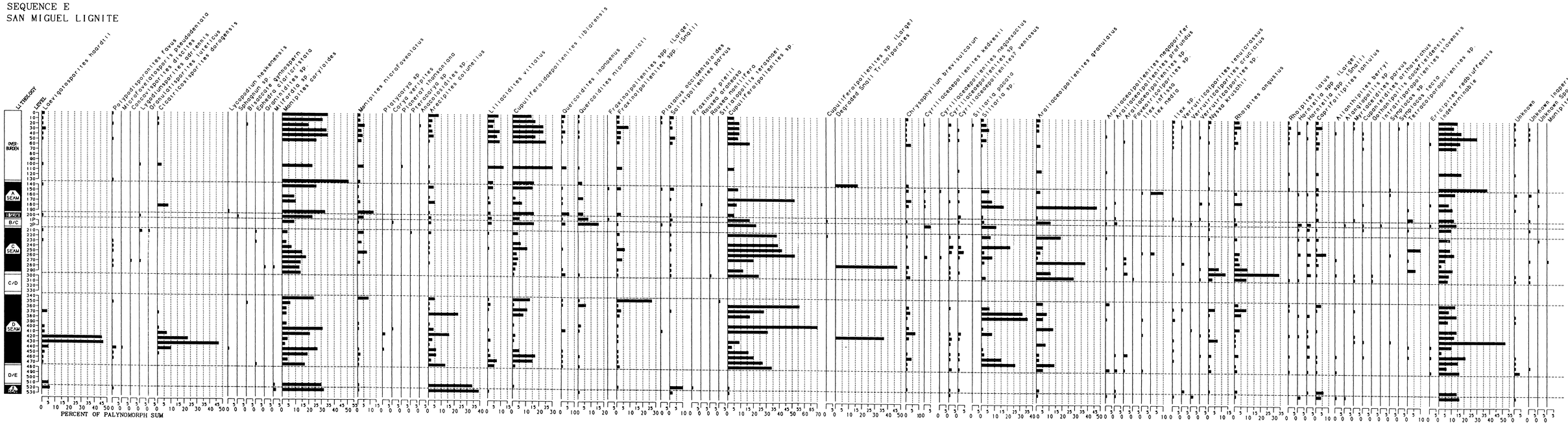


SEQUENCE F
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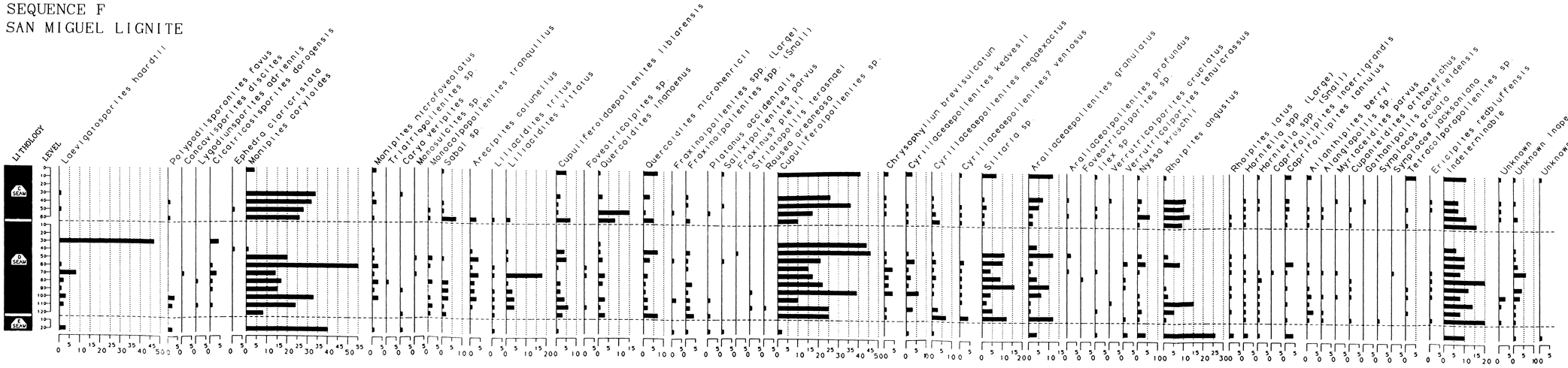


P3

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1993

# PLATE 4

## COMPLETE PALYNOMORPH DIAGRAMS OF G, H, AND SOMERVILLE SEQUENCES

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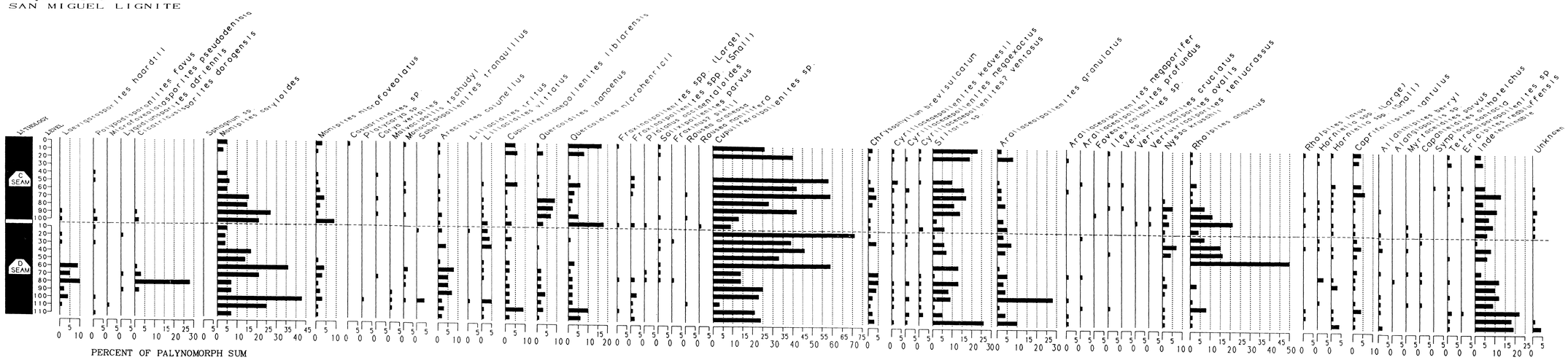
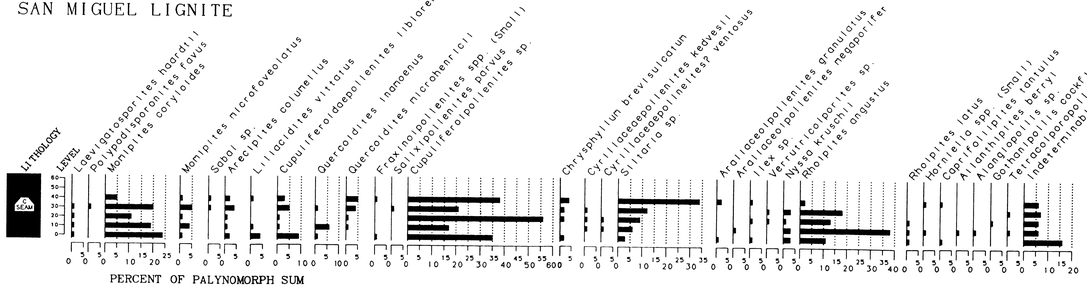



SEQUENCE H
SAN MIGUEL LIGNITE




LAKE SOMERVILLE SPILLWAY

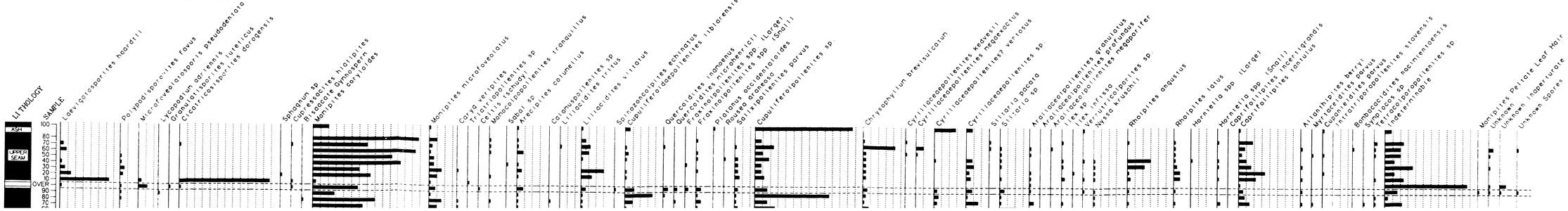


PLATE 2

# COMPLETE PALYNOMORPH DIAGRAMS OF A, B, AND C SEQUENCES

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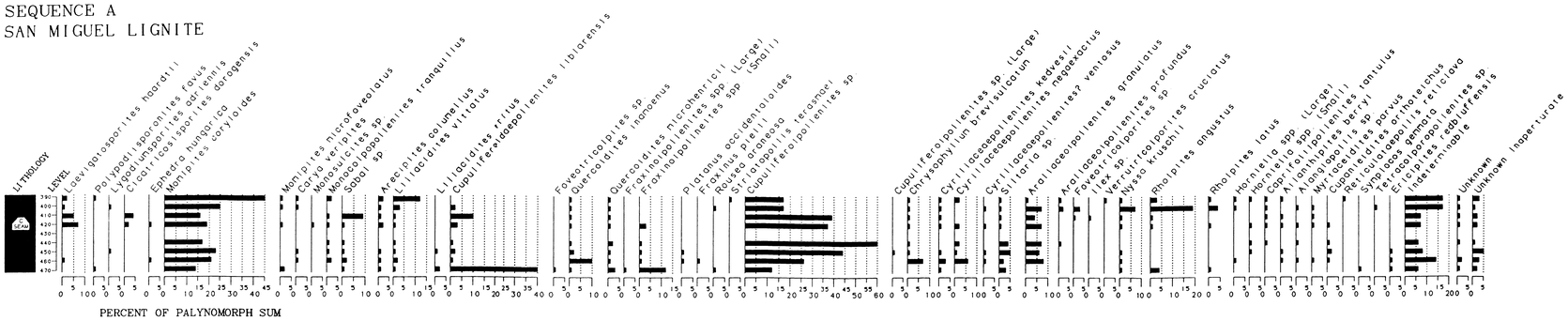
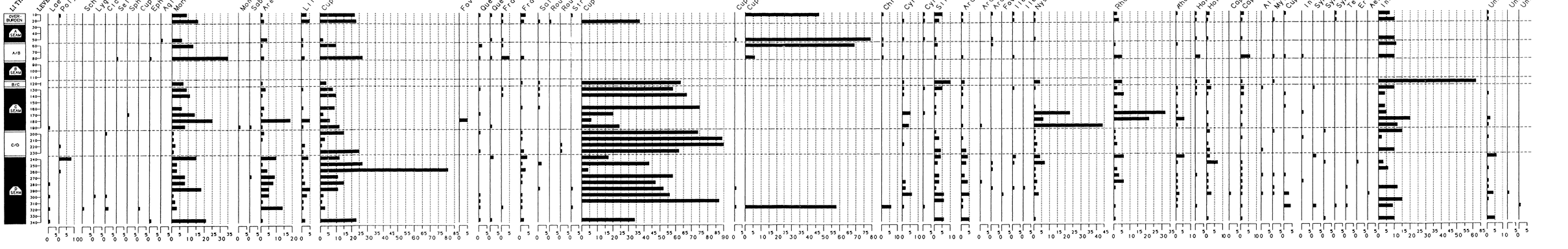



SEQUENCE B
SAN MIGUEL LIGNITE




SEQUENCE C
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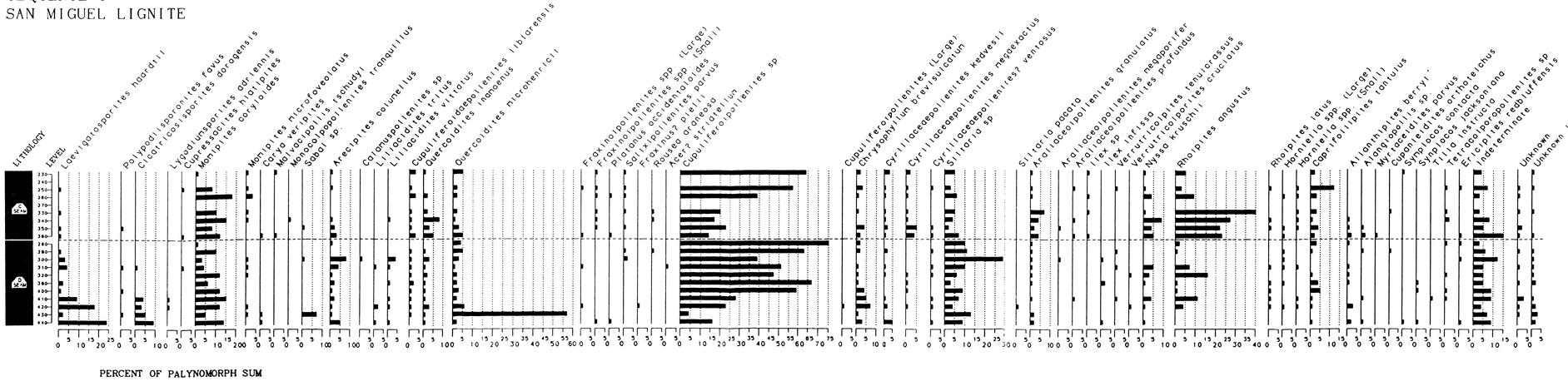


P2

Judith Ann Gennett
1993